The failure to act upon important information: where do things go wrong?

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The problem

1.1 Introduction

On a foggy day, the pilots of a commercial airplane prepared for the final descent. While approaching the landing strip, they performed all the necessary checks, such as the elevation level of the airplane and the current speed projected on the windshield's head-up display. However, even though both pilots were looking in the direction of the runway, they did not see the airplane emerging on their runway until it was too late to avoid a crash..........

Fortunately, the crash took place in a flight simulator in an experimental set-up, but the results were nevertheless shocking. In reality, this scenario would have led to major injury and possible death of passengers and crew. The pilots that participated in this study were not aware that the unexpected event was carefully planned (Haines, 1991). The most striking finding was not the fact that people do not see everything there is to see, but rather that they did not detect information that was in their central field of view, that was large, that was in the direction of their gaze and that was crucial for their own safety and the safety of their passengers.

While observing the world, people generally experience a richly detailed and structured representation of the world around them. The visual environment continuously confronts people with visual information, although not all information is useful or informative for our task at hand. For instance, when walking a street, there is no need to act upon all details in the surroundings in order to be able to keep walking. Nor are all colours or the types of cars that drive by relevant even though they could easily be identified if necessary. In these cases it seems only logical that an observer is not aware of all available information and does not feel the need to respond to it. However, in the example just provided, people fail to respond to information that is highly relevant for their task and which is considered to be clearly visible.

Unfortunately, this example is not unique in its kind. Reports of people involved in traffic accidents show that drivers claim that they did not see the other vehicle until they were so close that a collision was unavoidable. In the context of vehicle accidents this phenomenon has been called 'look-but-fail-to-see' (a.o. Staughton & Storie, 1977; Herslund, 1993, 2001; Jørgensen & Jørgensen, 1994). Even when the driver specifically looks for other traffic (for example when (s)he does not have the right of way) and other traffic is indeed present, drivers may simply fail to see it (Herslund & Jørgensen, 2003). The typical scenario of these 'look-but-fail-to-see' accidents is that a car driver approaches the intersection at a low speed and even often stops. The driver then decides to start driving again without having realised that other traffic, for instance a bicycle, is very close. Suddenly the bicycle is either right in front of the driver's car or runs into the car just when the car starts to move. According to the police, the car drivers are surprised and shocked since they

really feel they properly looked for the presence of other traffic (Herslund, 1993, 2001; Jørgensen & Jørgensen, 1994; Summala et al., 1996; Räsänen, Summala & Pasanen, 1998). Cairney and Catchpole (1996) claim that 70 to 80% of all intersection accidents results from these 'look-but-fail-to-see' accidents. A striking finding of these studies is that drivers not only 'fail to see' smaller objects such as bicycles, but also vehicles that one might expect to be easily detected, such as railway engines (Leibowitz, 1985) and buses (Draskoczy, 1989).

Similar examples are found in railway accidents. During a time period of 8 years, three severe railway accidents occurred in the Netherlands (described in Quist, 1988). The circumstances under which these accidents took place were comparable and they also happened on the exact same location. Because the trains passed this location with a speed that was far above the speed allowed, the trains became derailed, resulting in the three accidents. The conclusion from the accident analyses by the Dutch Railways was that there were no technical or mechanical failures. They claimed that the accidents were all caused by human error. Even though there were several indications that train drivers needed to reduce their speed, they did not do so. Apparently the drivers had failed to see the signal notifying them to reduce the speed of their trains to 40 km/h, which was the highest permissible speed at that point (crossing with other tracks). The failure to reduce speed resulted in severe material damage, one person was wounded and one person was killed.

The current thesis focuses on the phenomenon of 'the failure to apprehend'. The definition of this phenomenon is: Observers do not respond to information that is clearly visible and that is relevant for the task they are performing. This thesis studies the mechanisms underlying 'the failure to apprehend'. Chapter 1 through 6 will discuss literature related to this phenomenon and will illustrate the general principles of visual information processing to set a framework for the experimental studies. Chapter 7 through 12 will discuss the experiments that have been conducted in order to assess this phenomenon in more detail.

In the basic literature, there are two phenomena that are highly related to 'the failure to apprehend'; Inattentional Blindness and Change Blindness.

1.2 Inattentional Blindness

Inattentional Blindness refers to the tendency not to see unattended objects (Mack & Rock, 1998). In this definition the term unattended is essential. It indicates that one may look at an object without attending to it, as was the case in the flight simulator study. Hochberg (2007) claims that the term 'Inattentional Disregard' is more appropriate than Inattentional Blindness. Even though one may argue whether the

term 'blindness' is correct here, we will use this term since this is what is mostly used in the literature.

Most studies of Inattentional Blindness explore what type of information does or does not capture attention when observers do not expect the information to be present (Mack & Rock, 1998; Newby & Rock, 1998; Rock, Linnett, Grant & Mack, 1992). The example of the pilots that 'overlooked' the airplane blocking the runway is a clear example of Inattentional Blindness. Unfortunately, the sometimes dramatic results of Inattentional Blindness are not limited to the laboratory environment, as the following real life accounts demonstrate:

"A nurse pulls a vial from a cabinet. She looks at the label, fills the syringe and then injects the patient. The patient receives the wrong drug and dies." (Green, 2004).

"An Eastern airline pilot and his fellow officers see a bulb flashing on the control panel. They become so concerned with the cause, that they do not notice the plane approaching the ground or hear the alarms. The crash kills over 100 people." (Green, 2004).

"Road workers fail to see a dead deer on the road and actually pave over the deer. When fined by the police for this state felony, it turns out they did not even see the deer." (Most, Scholl, Clifford & Simons, 2005).

"Even though the commander of an American naval submarine claims to have looked into the periscope, he fails to notice a Japanese fishing vessel. Due to the collision, 9 Japanese people are killed." (Sciolino, 2001).

"In road accidents, drivers (sometimes) fail to see obvious obstacles in their way with dramatic consequences." (McLay, Anderson, Sidaway & Wilder, 1997).

All of these examples have one striking element in common: people fail to respond to information that is clearly visible and of utmost importance for them to respond to. In case of the nurse, she even specifically checked the label. Since the crucial information is clearly visible and of high importance, it is hard to imagine that someone can make such a huge mistake. However, 'the failure to apprehend' occurs more often than one may think.

Inattentional Blindness may happen to all people. Experiments show that most of our perceptual processing occurs without conscious awareness and Inattentional Blindness is simply part of how people process visual information. In a classic

experiment, Neisser and Becklen (1975) showed participants videos of two ongoing events simultaneously, each partially transparent and one superimposed on top of the other. By superimposing the two video images, the researchers guaranteed that the two scenes were presented at the same spatial location on the display and thus at the same location on the retina of the participants (for more details about the eye see Chapter 2). The two ongoing events showed different scenes. One scene represented two persons involved in a hand-slapping game, one player trying to slap the hands of the other player at irregular time intervals. The other scene involved three people throwing a basketball from one person to the other while moving around irregularly. The participants were divided in two groups: one group was asked to respond to every attacking stroke in the hand-slapping scene and a second group was asked to respond every time the ball was thrown from one person to the other in the basket-ball scene. After showing several regular trials, the researchers introduced an un-expected event in the scene that the participants were not specifically attending. For the hand slapping game this could be that the two persons stopped slapping hands and started to shake hands or that they started throwing a ball. For the basketball game it could either be that the ball disappeared and the players started to make fake throwing movements or that one by one the male players were replaced by female players. Most of the participants failed to notice these events, even though they were presented at the same spatial location as the attended scene. Only a few participants spontaneously mentioned seeing something odd, but even their reports were vague and incomplete. Even after being told what happened, half of the participants did not notice anything: the most common response was incredulity.

In order to further explore this phenomenon, Becklen and Cervone (1983) also con-fronted participants with two superimposed video scenes and with an unexpected event. In this case one of the scenes showed a basketball game with the players wearing white shirts, the other scene showing a basketball game with players wearing black shirts. Participants were either instructed to monitor the white team or the black team. Unexpectedly, a woman carrying an open umbrella walked slowly across the scene during 5 seconds, occupying the same spatial location as the other scenes. Quite a few participants did not notice this. In a similar type of experiment, participants were again instructed to monitor either the 'white' or the 'black' basketball team (Simons & Chabris, 1999). Unexpectedly, a third superimposed scene would either show a woman carrying an open umbrella or a person wearing a black gorilla suit. More than half of the participants never saw either event. After being explained what actually happened, participants watched the superimposed video images one more time. Most participants could not believe that they had not noticed this 'conspicuous' event.

In some studies of Inattentional Blindness researchers have turned to more controlled computer-based tasks in order to have a better control over the experimental condition (e.g., Mack & Rock, 1998; Most, Simons, Scholl & Chabris, 2000; Most, Simons, Scholl, Jimenez, Clifford & Chabris, 2001; Newby & Rock, 1998; Rock, Linnett, Grant & Mack, 1992). A number of studies used static scenes and brief presentations of simple shapes (e.g., Mack & Rock, 1998; Newby & Rock, 1998) in order to study Inattentional Blindness. In a typical experiment using a static display, Mack and Rock (1998) presented a cross to their participants. After a brief presentation only, the cross was replaced by a neutral masking stimulus. Participants had to indicate what was longer; the horizontal or the vertical line segment of the cross. After a few trials, an additional unexpected item appeared simultaneously with the cross in one of the cross's quadrants. Participants were asked whether they had seen anything else on that trial other than the cross. About 25% of the participants could not report seeing anything else, regardless of whether the unexpected item contained a unique colour, orientation, or motion signal. However, some meaningful stimuli, such as the participant's own name or a smiley were detected with greater frequency. Interestingly and counter-intuitively, higher rates of Inattentional Blindness (75%) were found when the cross was presented peripherally and the unexpected item was presentation at fixation.

In addition to static tasks researchers have also developed dynamic computerised tasks for studying Inattentional Blindness (Most, Simons et al., 2000, 2001; Scholl, Noles, Pasheva & Sussman, 2003). In a typical dynamic task, participants viewed a display with four black circles and squares and four white circles and squares moving randomly over, or even bouncing off the display. Participants were instructed to count the number of bounces of either the white or the black circles and squares. For the first two trials, this was all that happened. On the third trial, a red cross (different colour and shape than the original stimuli) entered the display. During 5 seconds, it horizontally moved from the right to the left side. Despite the discriminating characteristics of form and colour, almost 30% of participants failed to detect it (Most et al., 2001). In a study using letters rather than geometric shapes, Most et al. (2000) had participants count the number of times target letters came in contact with a line, while unexpectedly another stimulus (not being part of the stimulus set) moved horizontally across the entire line. More than half of the participants failed to detect this.

The studies cited above clearly point out that people are less aware of their visual surroundings than they think they are. The strength of this conviction is highlighted by the fact that most participants in the studies cannot believe having failed to detect the unexpected events when the event is explicitly pointed out. As Mack (2003) claims:

"(..) the pervasive assumption that the eye functions like a camera and the subjective impression of a coherent and richly detailed world leads most people to assume that they see what there is to be seen by merely opening their eyes and looking".

Mack assumes that this is also why people were so shocked to read about the virtual airplane crash in Haines' flight simulator study. They are not aware of the fact that there are numerous examples in every day live that demonstrate human limitations in visual perception.

1.3 Change Blindness

An interesting phenomenon that is related to Inattentional Blindness is Change Blindness (e.g. Mack & Rock, 1998; O'Regan, Rensink & Clark, 1999; Simons & Chabris, 1999; Simons, Franconeri & Reimer, 2000; Rensink, O'Regan & Clark, 1997; Rensink, 2000a; Hollingworth & Henderson, 2002; Rensink, 2002; Simons, 2000). Change Blindness has been defined as: the inability to spot changes to objects, photographs and motion pictures from one instant to the next (for a review see Simons & Levin, 1997). Although Inattentional Blindness and Change Blindness are related, they are distinct phenomena. Both phenomena involve the inability to report, detect or see visual stimuli that are obvious once they are attended to or pointed out. However, Inattentional Blindness deals primarily with first-order aspects of visual input (presence) while Change Blindness deals entirely to second-order aspects (transitions or changes).

In classical Change Blindness tasks, participants view a scene, followed by a disruption. This disruption can be an eye movement (e.g. Grimes, 1996; Henderson & Hollingworth, 1999a, 2003b), a blink (e.g. O'Regan, Deubel, Clark & Rensink, 2000), a blank screen (e.g. Simons, 1996; Rensink, O'Regan & Clark, 1997), a sudden 'mudsplash' on the screen (comparable to a sudden mudsplash on a car windshield) (e.g. O'Regan, Rensink & Clark, 1996), motion picture cuts (e.g. Levin & Simons, 1997; Simons, 1996) or a physical occluder (e.g. Simons & Levin, 1998). After the disruption, a modified version of the scene is shown, in which something has been changed. Participants are instructed to look for the change. Change Blindness experiments have shown that participants are surprisingly bad at detecting small and large changes to photographs or displays after brief interruption (Simons & Mitroff, 2001). When there is no disruption and the modified scene immediately follows the original, observers readily detect the change.

An alternative paradigm to study Change Blindness is the 'flicker' paradigm (e.g. Rensink, O'Regan & Clark, 1997). Here, the original and the modified scene are quickly alternated (e.g. 100-800 msec), separated by a brief blank interval.

This is repeated until the observer notices the change. The difficulty in detecting the change is measured by the number of repetitions before the change is identified: a high number of alternations indicates that the change was difficult to detect. Change Blindness has also been demonstrated in studies using longer intervals between the changes in scenes. For example: if one looks at the hands of a watch, seeing a change in position can only be done by attributing a new code or classification to the current position (O'Regan, 2001). The same also holds true for the situation in which one suddenly realises that the flowers on the table have wilted even though they wilted slowly all the time. Change Blindness in scenes that change extremely gradually (e.g. with grass in a picture growing very slowly) is not the focus of this chapter. In case of extremely gradual changes, the rate of change is assumed to be below the threshold of perception (Simons, Franconeri & Reimer, 2000), whereas this chapter focuses on change blindness items that are above threshold.

Where the phenomenon of Inattentional Blindness demonstrated that people may not always have an accurate representation of the visual world, the phenomenon of Change Blindness shows that even if they have an accurate representation, they may still fail to notice a change. Sometimes the change is not detected for several seconds, but suddenly snaps into awareness. Although it is tempting to explain Change Blindness by claiming that people did not look at the element that changed, O'Regan, Deubel, Clark and Rensink (2000) showed that this explanation does not hold. While monitoring eye movements of participants inspecting a scene, they found that even though it was easier for people to detect a change if directly looking at it, looking at it did not guarantee perception. Over 40% of the participants did not notice the change even though they were directly looking at it.

An interesting fact emerging from Change Blindness studies is that this phenomenon is not only found in artificial scenes, but also in natural scenes (Blackmore, Brelstaff, Nelson & Troscianko, 1995; Grimes, 1996; McConkie & Currie, 1996; McConkie & Zola, 1979; O'Regan, Rensink & Clark, 1996; Pashler, 1988; Rensink, O'Regan & Clark, 1997; Simons, 1996). For example, when people were looking at a photograph of a city skyline, Grimes (1996) found that none of the observers detected the enlargement of a prominent building by 25%. Rensink, O'Regan and Clark (1997) showed participants pairs of alternating photos of natural scenes, with one change from one photo to the next (e.g. element in the picture being removed). Although the changes were centrally located in the scene, they had to be repeated between 7 and 17 times before people detected them. Henderson and Hollingworth (2003b) had participants watch complex real-world scenes, in which changes were introduced from scene to scene. Participants were instructed to memorise the scenes for a later memory test and to immediately indicate every time the image changed. Participants even received descriptions of the type of change that could occur.

The changes were introduced at the moment that participants made eye movements. In about 3% of the cases, the changes were detected, which demonstrated nearly complete Change Blindness.

The fact that under specific conditions, people do not notice changes that are obvious once pointed out is specifically interesting in real movies. Imagine the following scene: An actor is sitting in a restaurant with a jacket over his shoulder. The camera cuts to a close-up and the jacket is now over the back of the actor's chair. Although this is a clear editing mistake, research shows that people are extremely poor at noticing these changes (Simons & Levin, 1997). In the USA, there was even a TV show dedicated to editing errors in Academy Award winning movies. Interestingly, the editing errors were presented as if the audience noticed the mistakes while filmmaker failed to. In reality however, they were only obvious because the host of the show always explicitly pointed them out to the audience. In fact, most people would not notice them while watching a movie.

This idea that people do not notice editing mistakes in movies has been used in experimental settings. Simons (1996) asked participants to watch a movie. The movie showed a woman sitting at a table pouring cola from a bottle in a cup. After this shot, the scene changed to a male actor approaching the table. In the third shot the cola bottle was replaced by a cardboard box. After watching the movie, participants were asked to describe aloud what they saw. Even though they reported seeing the bottle, they never reported the cardboard box or the change. Levin and Simons (1997) made a short movie with two actors having a conversation. In every shot, at least one editing mistake was included compared to the shot shown before. A woman wearing a scarf did not wear it in the next shot, whereas she would wear it again in the following shot. Actors changed their arm position from one shot to the next, food switched from one plate to the other etc. Participants were instructed to pay close attention to the movie, but when they were asked if they had noticed changes to objects, body positions or clothing, only one participant vaguely reported to have seen something change. Even if the movie was shown again, with participants now being aware of the fact that changes to the scene could occur, they only detected 1 or 2 changes out of the 9 present. One explanation for this phenomenon is that the changes were made to items that were not centrally located in the observers' field of vision, making it only reasonable that participants did not pay attention to these items. However, even changes to a centrally attended object are not always detected. Angelone, Levin and Simons (2003) had participants watch a movie in which a female actor asked someone for directions. Something that the woman wore or carried (a handbag, a purse) changed colour from one shot to the next. About 6% of the observers noticed the change. When two items were changed and the changes were made more salient still only 12% noticed the change. Levin and Simons (1997) used even more extreme
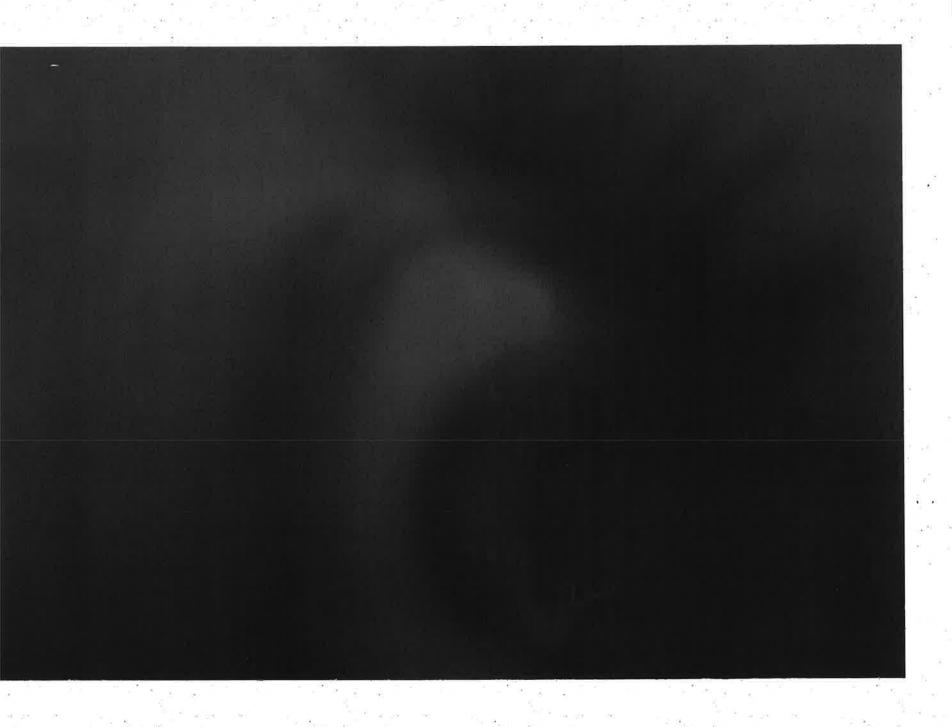
changes to the central object. In their movie, there was only one object moving in the scene, which was a person. The initial shot showed an actor hearing a phone ring. In the next shot, the phone was still ringing and the actor walked to the phone and answered it. However, in this new shot the actor was replaced by another actor (also partly wearing other clothes) who completed the action. About 33% of the participants noticed a change (any indication of change detection was taken as a right answer), indicating that the majority of the participants failed to. This finding was especially interesting since Dmytryk (1984) had claimed that under those conditions, participants are highly likely to attend to this person throughout the movie. The movie industry has recognised the human tendency to overlook changes and hired so called 'continuity editors' who check movies specifically for these types of editing mistakes. However, even continuity editors often fail to detect all of them, since there are large Hollywood productions with continuity errors.
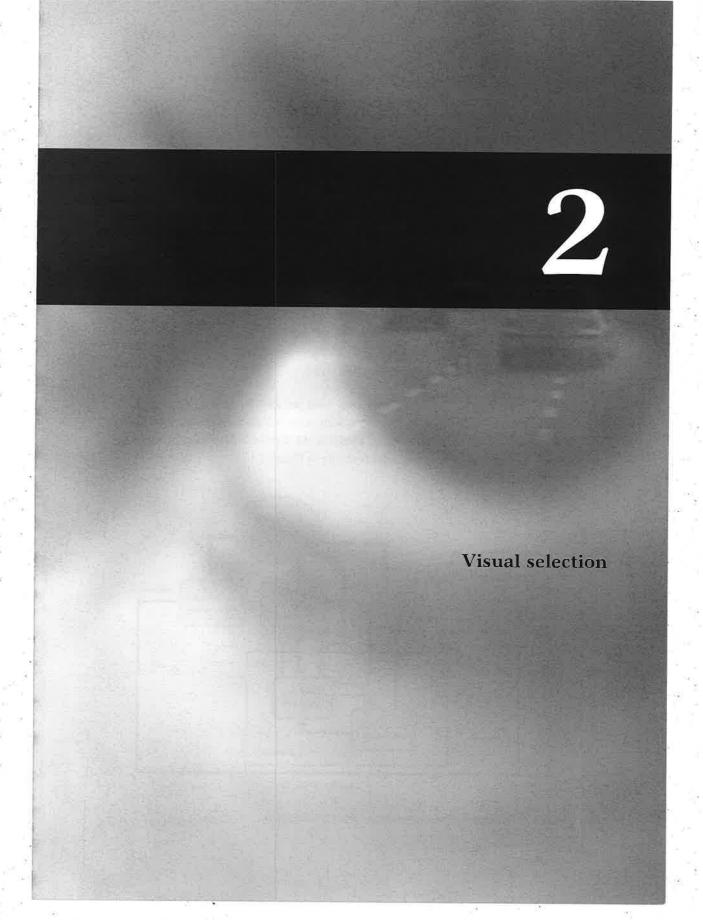
However compelling the examples from the movie industry and laboratory studies are, the question is, of course, how these examples relate to the real world. Maybe people observe movies differently than they observe the real world around them. Arguably movies are 'consumed' and observed in a more passive way. To study the phenomenon of Change Blindness in a more natural setting, Simons and colleagues (2002) used partly staged but real life situations. An experimenter carrying a basketball approached a naive pedestrian, with whom he started talking. During their conversation, a group of students passed between the experimenter and the pedestrian and secretly took away the basketball. After this event, the pedestrians were asked if they saw anything unusual or if anything had changed. Only a few pedestrians mentioned the disappearance of the basketball. However, when specifically asked if the experimenter was carrying a basketball before the interruption, more than half of the observers claimed to recall that. In another real life experiment (Simons & Levin, 1998) an experimenter would approach a naive pedestrian on the street and ask him or her for directions. While having this conversation, two people carrying a large door walked in between the pedestrian and the experimenter, shortly blocking the view that the pedestrian had on the experimenter. During this short period of time, the experimenter was replaced by a second experimenter, who wore different clothes. About half of the participants reported not to have noticed the change, even though they actively interacted with both the first and the second experimenter! Another real life study (Levin, Simons, Angelone & Chabris, 2002) also confronted participants with an unexpected person change when two people carried a door in between the participant and the experimenter (just like Simon & Levin, 1998). 38% failed to see the person switch. When the person switch took place after the experimenter had approached the participant to ask him/her to take his photograph, 53% missed the person change. In another of their experiments, an experimenter, after talking to the participant, duck back behind a counter. Another experimenter rose

from behind the counter at the same location. Here, 75% of the observers failed to see the person change.

In Change Blindness paradigms, people are often specifically asked to detect a change. They are in fact aware that a change will occur and they are required to actively search the displayed scene to find the differences. But despite the will to detect a change or the fact that the changed object is in the centre of attention, Change Blindness does occur. This shows that merely paying attention is not in all circumstances sufficient to actually detect the change.

The central theme of this thesis is 'the failure to apprehend'; the phenomenon that sometimes people fail to respond to clearly visible information even when it is highly relevant for their task. To study the underlying mechanism we further discuss related phenomena such as Inattentional Blindness and Change Blindness. Knowing the underlying mechanism allows us to develop countermeasures that may reduce the number of incidences of 'the failure to apprehend'.

2

Visual selection

The visual world that surrounds us is complex and detailed. This means that there is an almost continuous load on the human visual system, with many different objects being present. Despite the fact that each object is a potential target for action, responding to an object is only possible if the object is processed to a certain degree. However, not all objects surrounding us are processed. The visual system appears to be limited at some stage in the information processing cycle in the number of objects that can be processed for action. Although people may have the idea that vision is a simple sense and that all information that falls on the eye is perceived and allows the observer to act upon it, this is not the case. There is a certain limitation at some level of the information processing cycle. From all information that enters the visual system, some information is followed by a response whereas other information is not. A natural mechanism seems to select certain information for a response. Allport (1987) and Neumann (1987) state that 'selection for action' is a necessity resulting from our senses being capable of registrating different objects. Although theories do not agree where in the information cycle selection takes place, it is clear from all theories that selection plays a crucial role.

All human information processing models have sensory input (e.g. visual input) on one side and a response on the other, with some information processing stages in between. A well-known schematic model is the human information processing model of Wickens (1984). This model is shown in Figure 2.1.
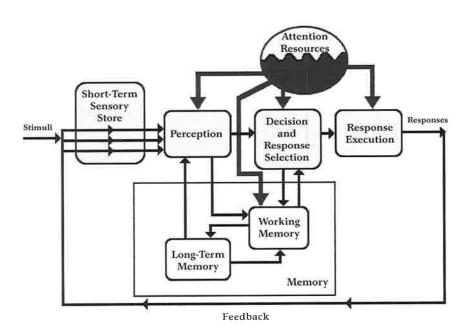

Figure 2.1 Human information processing model of Wickens (1984).

As Wickens claims, the model combines models presented by other researchers (e.g. Broadbent, 1958; Smith, 1968; Sternberg, 1969; Welford, 1976). Applying this model to the visual system, all visual information enters the short-term sensory store, preserving the physical stimuli for a short period of time without attention. The information is then processed, activating what was previously learned and stored in the brain. At this point the stimulus is said to be perceived or recognised. Once a stimulus has been perceptually categorised, the observer must decide what to do with it (decision and response selection), leading to response execution if a decision is made to generate a response. Selection is the process that takes place between what Wickens calls 'perception' and the decision and response selection.

Kahneman (1973) presents two models of selective attention. Model A assumes that all stimuli are transmitted to the stage of 'sensory registration and storage'. Only a selection of those stimuli is transmitted to the next stages 'perceptual analysis' and 'response selection'. The model illustrates aspects of the filter theory (Broadbent, 1957, 1958), assuming a bottleneck at or just prior to the stage of perceptual analysis. When two stimuli are presented, only one stimulus can be perceived immediately. The sensory information that corresponds to the other stimulus is held briefly as an unanalysed image. Only after the perceptual analysis of the first stimulus is completed can the observer attend to the other image to perceive it. Model B also assumes that all stimuli are transmitted to the stage of 'sensory registration and storage' but also claims that all information is then transmitted to the stage of 'perceptual analysis'. Only after this perceptual analysis phase, a selection is transmitted to the response selection phase.

Model B is associated with Deutsch and Deutsch (1963) who located the bottleneck only at or just prior to the stage of response selection, claiming that the meaning of all presented stimuli is extracted in parallel and without interference. The bottleneck prevents the initiation of more than one response at a time and selects the response that best fits the requirements of the situation. Kahneman already stated that some experimental results argue for model A whereas other results argue for model B, leading him to conclude that cognitive operations are far more flexible than either of these bottleneck theories suggest.

The two-stage approach (Treisman & Gelade, 1980; Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Theeuwes, 1992a) assumes that at an early stage, visual information is processed across the entire visual field in parallel without capacity limitations. A later attentive stage has a limited capacity and can deal only with one or a few items at a time. When items pass from the first to the second stage of processing, these items are considered to be selected, which is required in order to come to a response (Treisman, 1988; Duncan, 1980).

Even though different models locate the bottleneck at different locations in the information processing cycle, all models agree that there is a bottleneck somewhere in the information processing cycle. Selection is necessary to map specific visual information to a response.

2.1 What determines selection?

Not all information visually available is useful or informative for our task at hand. As discussed before, when walking a street, there is no need to process or respond to all details in the surroundings even though they could easily be processed or responded to if necessary. Performance would profit from automatic selection when relevant for the task at hand. Chapter 1 showed various examples of information that is crucial for the task at hand, without any selection for response execution. Apparently, the most informative regions of a scene are not automatically selected.

2.1.1 Attention

Attention plays an important role in selection. Attention has been described as 'the mechanism that accomplishes selection' (Yantis, 1998) and its main function is to facilitate perceptual processes (Tipper & Weaver, 1998; Broadbent, 1958; Treisman, 1988). Attention is also said to be a mechanism that selects stimuli for further higher-level cognitive processing (Cavanagh, 2004; Allport, 1993; Desimone & Duncan, 1995; Broadbent, 1958). As William James already noted in 1890, the object that people are paying attention to appears to receive more processing and is more richly represented in perception. Broadbent's (1958) classic filter theory states that perception only analyses the low-level physical properties of visual stimuli, such as colour, size, and motion. Higher levels of internal representation (e.g. recognition) are only achieved when attention is directed towards the perceptual representations of a particular object. Attention operates as a selective filter, by enhancing the perception of some stimuli at the expense of others present in the scene (Posner, Snyder & Davidson, 1980; Egeth & Yantis, 1997; Cepeda, Cave, Bichot & Kim, 1998; Pashler, 1998; Bahcall & Kowler, 1999; Cave & Bichot, 1999).

Actively capturing attention to the location of the change by means of spatial cues has shown to improve change detection (Scholl, 2000; see Simons, 2000 for a review), most likely by improving selection. In Angelone, Levin and Simons (2003) participants watched a movie in which an actor asked someone for directions. From this particular scene to the next, something the actor wore or carried changed colour. When participants were explicitly told that they had to pay attention to a specific area on the female actor, change detection improved by enabling selection. Inattentional Blindness experiments have shown a positive relationship between the spatial location of attention and the detection of information (Mack & Rock,

1998; Newby & Rock, 1998; Most, Simons, Scholl, Jimenez, Clifford & Chabris, 2001). The opposite condition, forcing observers to focus attention at a specific location on the screen via a secondary task, has been found to eliminate the ability to localise a change at another location (Fernandez-Duque & Thornton, 1999), most likely by disabling selection. Also non-location based aspects of attention play a role in detecting information in Inattentional Blindness studies. Information that has similar features to items that are attended has a higher chance of being detected. In an Inattentional Blindness study by Most, Simons, Scholl, Jimenez, Clifford and Chabris (2001), observers who attended to either white or black items in a display were more likely to detect an unexpected object when it was similar in luminance to the attended items and dissimilar to the ignored items. This attentional explanation is completely in line with the name 'Inattentional Blindness'; people are 'blind' to things in their visual surroundings because they are not paying attention to it. The most likely explanation is that due to inattention it was never selected.

2.1.2 Eye movements
Under normal conditions, selection takes place overtly by directing the eye to the visual information. Visual performance had shown to improve when targets occupy the location of an upcoming eye movement (Rizzolatti, Riggio, Dascola & Umilta, 1987; Rizzolatti, Riggio & Sheliga, 1994) and discrimination is best when the eye is directed to the object that has to be identified (Schneider & Deubel, 1995). When information is selected with attention only (without any eye movement), this is referred to as covert attention (e.g. Carrasco, Evert, Chang & Katz, 1995; Geisler & Chou, 1995; Verghese & Nakayama, 1994; Talgar, Pelli & Carrasco, 2004; Barrett, Bradshaw & Rose, 2003; Hunt & Kingstone, 2003). When the eyes are also moved to the spatial location, this is referred to as overt attention (e.g. Hunt & Kingstone, 2003; Bradley, Mogg & Millar, 2000; Henderson, 2003). Even though the existence of covert attention (the ability to pay attention to an object without actually fixating it) has been shown by various researchers (Von Helmholtz, 1909; Eriksen & Hofman, 1972, 1973; Hoffman & Nelson, 1981; Hoffman, Nelson & Houck, 1983; Posner, 1980; Yantis, 1998; Van der Heijden, 1992), it is generally agreed that there is a close link between attention and eye movements. When performing complex tasks, the eyes move almost continuously at an average rate of three to four times per second (e.g. Rayner, 1978; Tinker, 1939; Yarbus, 1967), suggesting that eye movements serve an important function in selecting visual information.

The close link between visual attention and eye movements has been shown in several studies (e.g. Henderson, 1996; Klein & Pontefract, 1994; Posner, 1980; Godijn & Theeuwes, 2002). Shepherd, Findlay and Hockey (1986) showed that when an eye movement is imminent, observers can only direct attention to the location that is the target for the saccade. The relationship is independent of whether the eye

movement is triggered by an external event, such as a sudden movement, or is internally directed by the participant on the basis of instructions or expectations (Hoffman, 1998; Hoffman & Subramaniam, 1995; Kowler et al., 1995; Posner, 1980). A number of studies have suggested that when an eye movement is observed from one object to the next, it can be concluded that attention has shifted as well (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Irwin & Gordon, 1998; Kowler, Anderson, Dosher & Blaser, 1995; Rayner & Pollatsek, 1992; Shepherd, Findlay & Hockey, 1986; McPeek, Maljkovic & Nakayama, 1999; Godijn & Pratt, 2002; Inhoff, Pollatsek, Posner & Rayner, 1989). All these studies argue against the decoupling hypothesis, i.e. the ability to direct visual attention to one location while simultaneously 'programming' an eye movement to another location. The decoupling would also seem unnatural from a biological point of view. Consider the visual orienting reflex that occurs in most large animals including humans to sudden lights or abrupt changes in the perceptual field (see Rohrbaugh, 1984 for a review). In this case eye movements would not be functional if the orienting reflex only attracted the eyes without any attentional focus. In nature, sudden changes in the perceptual field need to be selected immediately in order to come to a response (e.g. flee). In general, it is not possible to attend to one location while moving ones eyes to a different one (Deubel & Schneider, 1996). The competitive integration model (Godijn & Theeuwes, 2002; Theeuwes & Godijn, 2004; Godijn & Theeuwes, 2004) also assumes a strong relationship between attention and eye movements. It states that the perceptual processing of objects is facilitated if the object is selected as the goal for the eye movement.

2.2 The human eye

Obviously, the physiology of the eye plays a crucial role in how vision is accomplished. Light that passes the pupil encounters the lens, which together with the cornea and the pupil enables people to focus images on the retina, the light-sensitive tissue layer that lines the inner portion of the eye. Once images are focused on the retina, the eye nerve transports the visual signals to the brain. Even though the retina surrounds nearly 200 degrees of the inside surface of the eye ball, the central part of the retina that can process information in detail (with high resolution) is only small (Rayner & Pollatsek, 1992). This area is called the fovea, covering a region of about 1.5 degree of visual angle around a fixation point (Anderson, 1985; Cohen, 1981). The ability to process incoming information beyond this region decreases very rapidly (Van der Heijden, 1992). Even though the fovea is relatively small, the eye movement system enables the fovea to be directed to objects in the environment. By moving the eyes and head the fovea can be directed in rapid succession at one object after another, allowing clear vision for areas much larger than this 1.5 degrees of visual angle.

When discussing visual selection, not all eye movements play an important role. Due to the physical features of the visual system, many relatively small eye movements

(e.g. tremors, drifts and micro-saccades) are only necessary for keeping a clear focus without vision fading out. They do not play a role in what is selected. Three eye movement parameters are important in visual selection: saccades, smooth-pursuits and eye fixations.

1. Saccades are very rapid, jerky movements that bring information from peripheral retinal locations (where visual acuity is relatively low) to the foveal region. This allows the extraction of the highest quality visual information (Buswell, 1935; Yarbus, 1967; Henderson & Hollingworth, 1998; Land, Mennie & Rusted, 1999). These fast eye movements reach velocities as high as several hundred degrees per second and occur at a rate of about 3 to 4 per second.

2. Eye fixations are momentary or longer pauses of the eye at a particular position. Different criteria have been used to define a fixation. For example, fixations have been defined as eye movements remaining for at least 200 msec within a square of 2 degrees (e.g. Salthouse, Ellis, Dienier & Somberg, 1981; Moffitt, 1980; Widdel & Kaster, 1981). If one defines fixations as a momentary pause between two saccades, a fixation can be of any length without a minimum duration. Under normal conditions, the duration of a fixation represents the amount of time it takes to process the fixated information plus the time it takes to program the next saccade (for more details see 2.2.2). Under these conditions, fixations have a typical minimum duration of around 200 msec but can also be much higher (Findlay, 1997; Pollatsek & Rayner, 1982; Henderson & Hollingworth, 1998; Andriessen & de Voogd, 1973). Only under specific experimental conditions, much shorter fixations are found. Objects that elicit exogenous saccades, such as an abrupt visual onset, are fixated much shorter (Theeuwes, Kramer, Hahn & Irwin, 1998; Theeuwes, Kramer, Hahn, Irwin & Zelinsky, 1999). This is under conditions that an endogenous saccade to a target was already programmed and the onset interrupted moving the eyes towards the target. At the moment that the saccade was triggered to the target, the abrupt visual onset captured the eye. The fixation to the onset can be short since the programming for the next saccade (to the target) was already done before the abrupt visual onset. When discussing visual selection, the eye is assumed to be stationary during fixations since the tremors, drifts and micro-saccades that may be part of a fixation do not change the focus of attention.

3. Smooth-pursuits are slow smooth movements that keep the eyes fixated on a moving object (thereby being stationary relative to the moving object), generally at speeds well under a 100 degrees per second. In a typical smooth pursuit response to a target suddenly moving in the field, the eye and the target cannot be perfectly matched both in velocity and position at once (Westheimer, 1954; Rashbass, 1961). The 'position error' that occurs is partially corrected by a saccade. Basically smooth-pursuits are a combination of fixations and saccades for moving objects.

When dealing with natural viewing tasks, two relatively discrete temporal phases are distinguished, with fixations (periods of time when the point of regard is relatively still) and saccades (periods of time when the eyes are moving to reorient the point of regard from one spatial position to another) being of primary interest (e.g. Kroeber-Riel, 1992; Viviani, 1990; Van Duren, 1994; Gaarder, 1975). Even when following a moving object with smooth-pursuits, this pattern of fixations in combination with saccades has been found. This pattern of fixations and saccades is found in vision of humans, most other vertebrates and some invertebrates (Land, 1995; Land & Nilsson, 2002).

Eye movements are never randomly distributed over a scene but are related to the information or objects in the scene (Buswell, 1935; Yarbus, 1967; Humphreys, 1996). Without a specific visual search task, looking routines tend to select stimuli that are ecologically likely to be significant (Kahneman, 1973). Buswell (1935) was one of the first to show that fixations are concentrated on particular areas of interest in a picture. These findings are in line with the scanpath theory of Noton and Stark (1971a, 1971b, 1971c). This theory claims that in viewing, a particular repetitive sequence of eye movements is executed; a 'scanpath', being replicable over observers. This has been confirmed by other researchers (Lai, 1975; Locher & Nodine, 1973; Fisher, Monty & Perlmuter, 1978; Parker, 1978; Yarbus, 1967; Mannan, Ruddock & Wooding, 1997). When observers are instructed to identifying a briefly presented image, there is a high degree of similarity between fixations made by the same observer to different versions of a given image. Also for a given image there is a high degree of similarity between fixations made by the different observers (Mannan, Ruddock & Wooding, 1997).

Given the importance of saccades and fixations when scanning the visual world it is important to address what saccades and fixations can tell us about visual selection.

2.2.1 Saccades

During saccades, the human visual system is functionally blind. Saccades suppress the processing of visual information although processing is not entirely inhibited. This phenomenon is called 'saccadic suppression' (Matin, 1972, 1974; Volkmann, 1986, 1976; Becker, 1991; Shebilske, 1975; Irwin, Carlson-Radvansky & Andrews, 1995; Rayner & Pollatsek, 1992; Sperling & Weichselgartner, 1995; Wirtschafter & Weingarden, 1988). Common explanations are that such blindness rises from the rotational forces on the retina due to the speed of a saccade or that it may be caused by the velocity of visual details whiping across the retina during the eye movement. Without saccadic suppression, the motion of the image on the retina would prevent people from seeing anything (Kleiser, Seitz & Krekelberg, 2004).

What can saccades reveal about what is selected or attended? Humans make extensive use of rapid eye movements to direct the highest-resolution region of their foveated eyes towards locations and objects of current behavioural interest (Itti, 2005). The sequential attention model (Henderson, 1988; Henderson, 1992a; Henderson & Ferreira, 1990; Henderson, Pollatsek & Rayner, 1989) assumes that processing by means of covert and overt attention is closely coupled and that spatial attention precedes a saccade. In other words, directing attention to a location in space provides the endpoint of the saccade. Covert attention allows observers to select an object at its location before the actual saccade towards this object is launched. So if the eyes are going to move to a particular location (saccade), then attention was directed to that location first. The model claims that redirecting attention to a new stimulus coincides with the signal to generate a saccade to a new stimulus. The location of the stimulus towards which attention is redirected is equal to the location towards which the eyes are programmed to move. This has been confirmed by several others (e.g. Shepherd, Findlay & Hockey, 1986; Posner, 1980). Since a saccade from one object to the next can be interpreted as a shift in attention (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Irwin & Gordon, 1998; Kowler, Anderson, Dosher & Blaser, 1995; Rayner & Pollatsek, 1992; Shepherd, Findlay & Hockey, 1986; McPeek, Maljkovic & Nakayama, 1999; Godijn & Pratt, 2002), the end location of the saccade indicates what object is selected. Since it is not possible to attend to an object while moving the eyes to a different one (Deubel & Schneider, 1996), there is a close link between attention, saccades and selection. Rizolatti et al. (1987, 1994) found that oculomotor and attention control are supported by overlapping networks of brain regions. Their premotor theory of attention makes the strong claim that the neural structures for programming eye movements are the same structures that are used for programming shifts of attention. In addition neurophysiological evidence has been found to support the premises that there is a strong relationship between attention and eye movements (Kustov & Robinson, 1996; Corbetta, 1998; Moore & Fallah, 2001, 2004).

Summarising, saccades are required in order to align an object to the foveal area. Due to high resolution in the foveal area, moving an object to the fovea allows the object to be processed in detail. In natural viewing conditions, attention precedes saccades. Attention selects an object and the saccade follows, moving the selected object to the fovea. Therefore the end position of the saccade identifies the object that was previously selected by attention.

2.2.2 Fixations
As previously discussed, the eye is essentially blind during saccades. Therefore, fixations are of primary interest in studying visual selection since information is most likely to be acquired during fixations that intervene between saccades (Kroeber-Riel,

1992; Viviani, 1990). Kawabata, Yamagami and Noaki (1978) found a strong relation between what was fixated and what was reported, which was confirmed by Ellis and Stark (1978). Various studies have shown that people usually identify objects they fixate (see Rayner & Pollatsek, 1992 for a review), suggesting a close link between fixations and visual selection. In a variety of natural tasks, the relation between fixations, visual selection and action has been studied (Land & Lee, 1994; Land, Mennie & Rusted, 1998, 1999; Hayhoe, 2000; Land & Furneaux, 1997). Tasks studied are driving (Land & Lee, 1994), table tennis (Land & Furneaux, 1997), piano playing (Land & Furneaux, 1997) and tea-making (Land, Mennie & Rusted, 1999). The results all demonstrate that fixations are almost exclusively linked to objects that observers interact with when performing the task, with very stable findings over participants.

There are several theories that address the relationship between fixation duration and information processing. According to the immediacy hypothesis (Just & Carpenter, 1980) processing of a currently fixated signal is complete prior to the start of the saccade to the next signal. In that case glance durations accurately reflect the time needed for processing the fixated signal, and variations in processing requirements of a signal would affect its fixation duration but not the duration of subsequent fixations. The sequential attention model (Henderson, 1988; Henderson, 1992a; Henderson & Ferreira, 1990; Henderson, Pollatsek & Rayner, 1989) claims that at the beginning of fixating a new stimulus, attention is allocated to the stimulus, but that as soon as the processing of the fixated stimulus is completed, attention is redirected to a new stimulus. This all seems to be in line with empirical evidence showing that fixation duration depends on the amount of processing during a fixation (Just & Carpenter, 1980; Rayner, 1977; Rayner & Duffy, 1986; Paap, McDonald, Schvaneveldt & Noell, 1987; Inhoff, 1984; Carroll & Slowiaczek, 1986).

In the current thesis, the term 'glance' or 'glance duration' will be used to describe the point of gaze and the duration of the gaze. This term is used in order to avoid discussing whether particular eye movement behaviour should be labeled a fixation, a saccade or a smooth pursuit. The term glance will be used to indicate what someone gazes at, irrespective of whether this is fixated, fixated interrupted with saccades while gazing at the same object or whether the gaze is following a moving object. The main interest in this thesis is visual selection and how it leads to a response. Since fixations, saccades to a location and smooth pursuits all point to the same phenomenon, that is that something is selected, a distinction between these three types of eye movements is not required for the current research theme.

2.3 What controls the eye?

If eye movement behaviour represents the way we select information from the environment the next question is how and in what way is the eye controlled. Do people have full control over what is attended or selected?

Literature has shown that selection may either be controlled by the properties of the stimulus field or by intentions, goals and beliefs of the observer (see Egeth & Yantis, 1997; Theeuwes, 1993, 1994, Eriksen & Hoffman, 1972; Posner, 1980; Yantis & Jonides, 1984; Yantis, 1996, 2000; Abrams & Jonides, 1988; Findlay, 1981; Fischer & Weber, 1993; Shepherd, Findlay & Hockey, 1986). Attention or selection is said to be 'bottom-up' (or exogenous or stimulus-driven or passive) when it is controlled by some salient stimulus attribute that is not necessarily relevant to the observer's perceptual goals or the task at hand. Attention or selection is said to be 'top-down' (or endogenous or goal-driven or active) when it is controlled by the observer's deliberate strategies, intentions, goals and expectations. In this respect, the term conspicuity is often mentioned. The conspicuity of an object represents how much an object stands out from its surrounding environment. How much an object stands out depends on whether an object is able to draw attention without an observer looking for it (so called 'object conspicuity', Hughes & Cole, 1986, related to bottom-up selection) or how easily it is selected when an observer is actually looking for it (so called 'search conspicuity', Hughes & Cole, 1986, related to top-down selection).

2.3.1 Bottom-up selection

Selection is said to be bottom-up when selection is controlled by some salient stimulus attribute that is not necessarily relevant to the observer's perceptual goals or the task at hand. Such an object automatically forces itself to be selected, possibly eliciting an eye movement toward the object. As soon as the eye is close to a salient object, the object automatically attracts the eye (Engel, 1977). As mentioned before, this is also called object conspicuity; the capacity of an object to attract attention even though the observer is not specifically looking for the object. Since salience does not depend on the goal of the observer, many researchers have tried to determine objective salience criteria by having participants watch videos or images in a free-search paradigm. By computing saliency maps (Koch & Ullman, 1985; Niebur & Koch, 1996; Itti, Koch & Niebur, 1998; Itti & Koch, 2000), it is possible to determine the degree to which eye movements are drawn by stimulus properties alone.

An example of a bottom-up feature is for instance size. If a target is very large compared to its background, this may render the object conspicuous (Engel, 1974, 1977; Forbes, Fry, Joyce & Paine, 1968a, 1968b; Paine, 1969). Also, the complexity of the background plays a role (Boynton & Bush, 1956; De Jong & Duijnhower, 1972).

People tend to fixate an isolated object in the field even when it carries no information (Kahneman, 1973). Adults have also shown to retain an extremely powerful tendency to direct their eyes toward a moving object and to scan contours (Kahneman, 1973). Attention is automatically attracted by unique features (Treisman & Gelade, 1980), abrupt onsets (Yantis & Jonides, 1984; 1996) and the appearance of new perceptual objects (Hillstrom & Yantis, 1994) even when irrelevant to the task at hand.

The strong effect of bottom-up selection is illustrated in cases where objects cannot be ignored even when the observer is searching for something else. Theeuwes (1991a, 1992b) used visual search tasks in which participants had to select an item with a specific unique feature (e.g. green circle amongst green squares, top-down search). A known to be irrelevant distractor with a unique colour (e.g. red square) could not be ignored, showing strong bottom-up selection. Even after extensive training, this bottom-up effect of the irrelevant item was still present (Theeuwes, 1992b). Pashler (1988) also found an interfering effect of a distractor with a unique colour on finding a target with a unique form. Yantis and Jonides (1984) demonstrated that the visual system is selectively sensitive to visual stimuli that are presented with an abrupt onset. When searching a display for a specific target, abrupt onsets were always selected first. Onset stimuli were identified much faster than no-onset stimuli, with the abrupt onset drawing attention to this location. In this respect it is not the onset per se, but rather the stimulus onset transient (which can also be an abrupt offset) that attracts attention (Jonides & Yantis, 1988; Yantis & Jonides, 1984; Miller, 1989). Peripheral cues with abrupt onsets elicit a bottom-up shift of attention to that location, without participants being able to ignore this abrupt onset when explicitly instructed to do so (Jonides, 1981). Theeuwes (1990) also showed that an abrupt transient change of form induced an unavoidable 'pop-out' suggesting that attention is drawn to the source of change. Changing the colour of equiluminant stimuli did not result in bottom-up selection. Müller and Rabbitt (1989) found that allocating attention to a specific location could not prevent a shift of attention to an abruptly changing flash.

Bottom-up salience can be used to enhance selection in case of a stimulus of high importance. Important signs or warnings can be made big and bright in order to attract attention. Objects that stand out from their background can successfully compete for attention with other objects in the scene. Bottom-up selection is also what advertisers use for drawing attention to their advertisements. By using bright colours, flashing lights and moving items it is assumed that the information is automatically attended, even if people are not specifically looking for that informa-tion. The conspicuity of an object has therefore also been defined as its ability to attract attention without the need for any search (Jenkins, 1982) or the attention-getting value (Holmes, 1974). The fact that advertisements are capable of attracting attention while searching for something else was shown in an experiment by Cole

and Jenkins (1982). Even though observers were specifically instructed to search for specific objects placed in the driving scene, conspicuous non-task related items such as advertisement signs attracted overt attention. This shows the strength of bottom-up processes even in case of top-down search.

In this respect, using an unpredictable content or a strange item in an advertisement may also work to get attention. Mackworth and Morandi (1967) claim that areas with a high informational value or an unpredictable content are the ones being spontaneously inspected in the context of picture viewing. This relationship between informative regions and observers' fixation clustering has been replicated by several researchers (Zusne & Michels, 1964; Antes, 1974; Buswell, 1935; Yarbus, 1967). A problem is that the definition of informativeness is often subjective (Buswell, 1935; Yarbus, 1967; Antes, 1974; Mackworth & Morandi, 1967). 'Informative' has also been used to define objects that do not fit the scene (Friedman, 1979; Henderson, Weeks & Hollingworth, 1999; Loftus & Mackworth, 1978), with longer glance durations for objects that are unlikely in the scene (Friedman, 1979; Henderson, 1992a; Henderson, Weeks & Hollingworth, 1999; Loftus & Mackworth, 1978). Observers tend to return their gaze to semantically informative regions over the course of scene viewing (Loftus & Mackworth, 1978; Henderson, Weeks & Hollingworth, 1999). Other studies found a more complicated relation, with incongruous information not having a higher probability of being fixated, but once fixated they result in longer fixations (Friedman & Liebelt, 1981; De Graef, Christiaens & d'Ydewalle, 1990; Henderson, Weeks & Hollingworth, 1999).

When the conspicuity of an item is very large, the bottom-up selection may take attention away from other items. When the conspicuous item is relevant for the task, it enhances performance. On the other hand, when the conspicuous item is irrelevant but forces itself to be selected, relevant information may suffer. Take for example the case of advertisements (i.e. billboards). In driving, advertisements with odd messages, flashing lights or moving images may ask for attention while the information is completely irrelevant for the driving task. In this example, the bottom-up features of the advertisement may even cause dangerous situations. In this case 'the failure to apprehend' may be the result of other irrelevant information being selected in a bottom-up manner.

2.3.2 Top-down selection

Obviously, bottom-up selection only represents one side of the coin. Selection can also be under top-down control. When William James first introduced his notions on attention in 1890, he called this type of attention 'active'. Top-down selection takes place when people select objects from a scene that share features with the specific target object they are looking for (e.g. Treisman & Gelade, 1980; Wolfe et al., 1989; Findlay, 1997). As mentioned before, this is also referred to as search conspicuity,

which is the capacity of an object to be found if the observer is specifically looking for this target. Observers who were instructed to attend to circles were more likely to detect an additional circle (82%) than observers attending to squares (6%) (Most, Clifford, Scholl & Simons, 2000). This is also in line with the fact that in the Simons and Chabris study (1999), mentioned in Chapter 1, the top-down selection of the black basketball team in one of two superimposed video scenes resulted in better detection of the black gorilla walking across the scene than those observers using the top-down selection of the white basketball team. Most, Clifford, Scholl and Simons (2000) found that instructing observers to attend to a black instead of to a white shape lead to a higher chance of perceiving an additional black circle. That top-down selection is strong is shown by the fact that even items with a unique brightness, colour or shape do not automatically attract attention. These features that normally pop-out if they are relevant for the task do not capture attention when they are irrelevant for the task, showing control by the observers' intentions (Jonides & Yantis, 1988; Theeuwes, 1990).

When searching for an object in a scene, people first search at the likely locations for these objects. Obviously, this is search that is clearly under top-down control. Search for an object at a non-predictable location was much slower than search for an object at a likely location (e.g. a saucepan under a table) (Meyers & Rhoades, 1978). Searching for traffic signs located on the left (unexpected) side of the road lead to a high number of misses and increased search times (Theeuwes, 1991c). Observers searched on the right side of the road where traffic signs are normally located. Pearson and Schaefer (2005) found that emphasising the driving aspect in a photo change detection task changed participants' top-down search. Participants performed better on detecting driving-relevant changes than participants without this instruction. In driving scenes, participants are faster in detecting driving related changes than driving unrelated changes (Richard, Wright, Ee, Prime, Shimizu & Vavrik, 2002). Yarbus (1967) also found that the way observers scan a picture depended on the instructions that the observers received. When instructed to estimate the material circumstances of a family in the picture, fixations were distributed widely over the scene. When instructed to guess the age of people in a picture, observers concentrated their fixations specifically on faces. Research on expert performance clearly shows the strength of top-down selection. Because of their attentional set, experts primarily focus on domain-specific stimuli whereas non-experts may also pay attention to other stimuli. Experts in American football were faster at detecting changes in photographs related to football than novices (Werner & Thies, 2000). Chess masters have better immediate memory for chess-related information with brief exposures (De Groot, 1978; Chase & Simon, 1973a, 1973b), expert chess players are better in detecting changes related to the chess play than novices (Reingold, Charness, Pomplun & Stampe, 2001) and experienced drivers are better in detecting driving-relevant changes compared to non-driving task related changes

(Groff & Chaparro, 2003; Pearson & Schaefer, 2005). These results suggest that intentions, goals and expectations guide selection and thereby perception.

However, this top-down selection, ruled by intentions, goals and expectations may also introduce a problem. Consider the following example of Sarter and Woods (1997). In the cockpit of highly automated aircraft, pilots failed to detect changes in an automation configuration when the automation took an unexpected action. Since this was not part of the top-down selection strategy, it was not inspected and therefore not detected. Pilots reported that they looked where they expected to find changes. So if the top-down strategy is adequate for the task at hand, selection or detection is rather effective and fast, but in case of an incorrect top-down strategy, selection or detection may be absent.

Although the distinction between bottom-up and top-down control is important, it is equally important to recognise that any given act of attention typically involves some combination of the two attentional modes (Yantis, 1998; Itti, 2005; Itty & Koch, 2000; Parkhurst & Niebur, 2004).

2.4 Conclusion

Selecting the right information for the execution of a task is very important. Even though all information available in the world around us falls on the retina, only some information is fully processed. Only selected information is able to generate a response. Since there are many examples in which people do not select the right information, the phenomenon of 'the failure to apprehend' can often be found. Selection may not have taken place because other more conspicuous information may draw away attention from the relevant information. Or even though relevant, particular information may not be part of our top-down search strategy, thereby never entering the next information processing stage to such an extent that it can result in a response.

The concept of attention plays an important role in visual selection processes. Directing attention to an object implies that the object is selected and thereby available for further processing. In this respect, attention operates as a selective filter, leading to more elaborate processing of some stimuli at the expense of others. Attentional selection can take place covertly (without the eyes fixating the location that one attends), but in most cases, attention and eye movements are closely linked. In natural viewing tasks, attention precedes the eye. When a saccade is made to a specific object, the object is first selected by attention. A fixation to a specific object is the end position of a saccade and indicates that this object has been selected. The duration of a fixation has said to indicate the time required to process the information.

3

Perceiving and responding

'The failure to apprehend' may have serious consequences. Chapter 2 discussed that selection plays a crucial role in generating a response, explaining 'the failure to apprehend' by the information not being selected. However there are also instances where information is selected, but there is still no response. Chapter 3 discusses the theoretical notion that information can be selected even though it does not lead to a response. An important question is why there is no response despite selection.

3.1 Evidence for processed information

There is evidence that in some cases, information is selected and even processed without resulting in an appropriate response. Some examples will be given in this paragraph.

3.1.1 Evidence from forcing a response

In many change detection tasks, observers are asked to determine whether objects have changed from one display to the next. In many of those cases, observers claim that they did not respond because they did not perceive any changes in the visual field. However, observers are better than chance in selecting changed items even if they claim that they did not 'perceive' any changes (e.g. Fernandez-Duque & Thornton, 2000; Mitroff, Simons & Franconeri, 2002; Fernandez-Duque & Thornton, 2002).

In an experimental study, observers were confronted with a circular array of horizontally or vertically oriented rectangles (Fernandez-Duque & Thornton, 2000). After a brief interruption, a change was introduced, which was the rotation of one of the rectangles by 90°. Observers had to select which of two items had changed. Even in cases in which observers claimed not to know the answer, they still selected the changed item more often than the non-changed item in a forced-choice task. In another study (Thornton & Fernandez-Duque, 2000) a change detection task was used, with one out of 8 items changing in orientation. Even when observers reported not to see any change in an item's orientation, it still positively biased their response in the orientation discrimination task.

A third study that showed that information may be processed without resulting in a response comes from Mitroff, Simons and Franconeri (2002). They presented observers with changing displays in a flicker task. On 75% of the trials one item in the display rotated in the picture plane. Observers were asked to respond when they detected a change, after which they had to indicate which item (location) had changed. Even those observers who did not report a change correctly selected the changed item above chance level when they were forced to respond.

VanRullen and Koch (2003) showed observers a brief presentation of 10 objects. When asked to recall as many items as possible, observers were able to recall an

average of 2.5 objects. However, when observers were forced to make a choice out of a set of objects, there correctly selected 5 objects. The other 5 objects that were not recalled or recognised were still processed to some extent, since they resulted in negative priming in a later task.

Also in real life studies, observers appear to process more information than they spontaneously report. For example in a study by Simons, Chabris, Schnur and Levin (2002) participants were approached by an experimenter that asked for directions to the gymnasium. When a participant started to give directions, some people passed between the experimenter and the participant. In some cases, they took away the basketball that the experimenter was holding. Only about 1/3 of the participants spontaneously mentioned the disappearance of the basketball if they were asked if they noticed anything unusual or if anything had changed. This means that the conclusion that 2/3 of the participants did not detect the change can quickly be drawn. However, twice as many people correctly reported the change if they were asked leading questions. This means that far more information was processed than participants initially used for their response. This is in line with the other studies that show evidence for the processing of information if people are forced to choose even though they cannot spontaneously claim to be aware of the information.

3.1.2 Evidence from fixations

Fixation duration is also affected by changes in a scene, even without observers responding to the change. In one study, observers were asked to look at black and white line drawings of complex naturalistic scenes (Hollingworth, Williams & Henderson, 2001). They were instructed to immediately report any change to the drawings by pressing a key. On some trials, objects were replaced as the eyes of the observer moved away from this particular object. When the eyes returned to the changed object, mean fixation duration was longer in the change condition than in the control condition that did not have a change. This was the case even in the absence of explicit detection, so even when observers could not report the change. This was also found in a block-copying task (Karn & Hayhoe, 2000). Participants had to build an exact copy of a shown model of coloured blocks as quickly and adequately as possible on a separate workspace. On some occasions, all blocks previously placed on the workspace disappeared for a short period of time when participants fixated the model. These blocks reappeared during the next saccade towards the workspace. The total glance duration for a block was longer in the disappearing condition compared to the non-disappearing condition, even though participants could not always report the disappearance. This study demonstrated that even without being able to report it, changing information resulted in higher fixation duration.

In a study of Ryan, Althoff, Whitlow and Cohen (2000) observers viewed a series of images of real-world scenes while eye movements were recorded. After viewing

these images, observers were presented with new scenes that had not seen before, scenes they had seen before and scenes with a change compared to what they had seen before. Observers were not informed about the possible appearance of changes. The results showed that in scenes with a change, eye movements were drawn to the changed region, with a greater proportion of fixations and of total viewing time. Also, an increased number of saccades were made to and from the critical region compared to the exact same scenes or completely new scenes. This effect could be observed without observers being able to report any changes. Ryan and Cohen (2004) showed that different types of manipulations to real-world scenes lead to different results. The three types of scene manipulations they used were (1) the deletion of an object, (2) the addition of an object or (3) a shift of an object from the left side of the scene to the right side, or vice versa. For all changes, fixations were directed relatively early to the region that had undergone the change, with longer glance durations and a larger number of fixations to the changed region. When a new item was present (addition or left and right switch), the newly occupied region received more viewing than when an item was deleted. Many other studies have found this increase in glance duration for changed items (Hollingworth & Henderson, 2002; Karn & Hayhoe, 2000; Hayhoe, Bensinger & Ballard, 1998).

These studies using eye fixation as a dependent measure have shown that there may be information processing without observers reporting the change, showing that 'the failure to apprehend' does not necessarily mean that the information was not processed.

3.1.3 Evidence from brain potentials
Some studies use brain potentials to measure whether information is processed. Event-related potentials (ERPs) are known to accompany the detection of low-probability targets (Johnson, 1986) and are thought to reflect a range of cognitive processes, including recognition and identification (Vogel et al., 1998). Interestingly enough, ERPs measured in Change Blindness studies seem to be related to the ability to report the change. For example, the P300 component of ERPs is found in consciously detected changes. This brain potential is absent both in cases of Change Blindness and in control trials where no change is present (Turatto, Angrilli, Mazza, Umilta & Driver, 2002, Fernandez-Duque et al., 2000; Niedeggen et al., 2001). Eimer and Mazza (2005) found that the P300 is primarily related to variations in the confidence of the observers' perceptual judgments and not by conscious change detection as such. They found that the N2pc component of the ERP was the most direct electro-physiological correlate of conscious change detection. The N2pc component was elicited on detected change trials but was entirely absent on undetected change trials.

Many researchers have used brain potentials to study whether a change has been processed (Donchin & Coles, 1998; Luck et al., 2000; Vogel, Luck & Shapiro, 1998; Koivisto & Revonsuo, 2003; Niedeggen et al., 2001; Turatto, Angrilli, Mazza, Umilta & Driver, 2002; Fernandez-Duque et al., 2000; Fernandez-Duque, Grossi, Thornton & Neville, 2003). Specific brain activity has been found in response to changes or to new information without the observer being able to report it (Beck, Rees, Frith & Lavie, 2001; Dehaene, Naccache, Cohen, Le Bihan, Mangin, Poline & Riviere, 2001; Vuillemier et al., 2001; Fernandez-Duque, Grossi, Thornton & Neville, 2003; Eimer & Mazza, 2005). These studies suggest that visual information is processed in specific regions of the brain without people being able to report the information.

The magnitude and latency of an ERP vary as a function of the physical and informational properties of a stimulus as well as the observers' cognitive response to the stimulus (Israel, Wickens, Chesney & Donchin, 1980; Callaway, Tueting & Koslow, 1978; Donchin, 1979; Donchin, Ritter & McCallum, 1978; Picton, Hillyard, Krausz & Galambos, 1974). The amplitude of an ERP is often used as an illustration of the level of processing. For instance, when people have to deal with a second stimulus shortly after the presentation of a first stimulus, there is a suppressed P300 wave (Luck, 1998). This is seen as evidence that processing of one stimulus interferes with the processing of the other, resulting in a lower amplitude. Wickens, Israel and Donchin (1977) demonstrated that the amplitude of the P300 component was reduced by the load imposed by the concurrent tracking task, also indicating that increased workload decreases the amplitude of the ERP.

Uetake and Murata (2000) found that fatigue is associated with a decreased P300 amplitude and a prolonged P300 latency. The prolonged P300 latency indicates delayed cognitive information processing and the decreased P300 amplitude is related to the decreased activity of cognitive information processing. Intoxication (alcohol) also causes a significant reduction in amplification of the novelty-P300 signal in car drivers compared to sober drivers (Rakauskas, Ward, Bernat, Cadwallader, Patrick & de Waard, 2005). However, talking on the cell phone while driving showed an even larger decrease in the ERP amplitude, suggesting that people driving and talking on the phone are cognitively impaired, especially in terms of evaluating sudden and unexpected stimuli (Rakauskas et al., 2005).

ERPs are therefore not only useful as an indication that a stimulus is processed but also to identify the level of processing by measuring ERP amplitude and latency. This way it is possible to estimate the level of attention, task load, fatigue or intoxication.

3.1.4 Evidence from priming

If it is indeed true that information can be processed without the observer being able to report it, then the processed information may influence later stages of processing. In Change Blindness experiments, the response is almost always a verbal report that a change has occurred. Examining the effect of the presentation of a stimulus on the processing of a subsequent stimulus – so called priming effects – provides another way to examine the fate of processed stimuli that did not lead to a verbal response.

Mitroff, Simons and Franconeri (2002) found some form of implicit learning, thereby showing that information was indeed processed without observers being aware of the information. Change detection was found to improve after observers had seen more trials of the same pictures. Even when observers indicated to guess, change detection rates were about 16% on the first trial 1, increasing to 26% on trial 6, a performance level well above chance.

Thornton and Fernandez-Duque (2000) found evidence of an implicit effect of cueing on change detection. Observers viewed a display with an array of rectangles. After a blank screen another display with rectangles appeared either with or without a rectangle having changed orientation from vertical to horizontal or vice versa. Immediately after the change, one of the rectangles was briefly cued and observers were asked to report the orientation of the cued rectangle. It was found that observers made more errors in naming the orientation of the cued item when its orientation was different from that of the changed item, even if they did not consciously detect the change. This indicates some form of negative priming without explicit change detection.

Chun and Jiang (1998) showed that representations may directly influence behaviour. Participants found a target more efficiently when they had seen the search array before, even when they did not recognise the display. This benefit represents a form of implicit learning or positive priming effect (Lewicki, Hill & Czyzewska, 1992; Reber, 1989; Stadler & Frensch, 1998). Despite the fact that in a forced choice recognition test, the observers could not discriminate the old from new contexts, the previously seen context improved search performance.

3.2 Why is there no response?

If visual information is not selected for further processing, it is not able to generate a response. However, the previous paragraph described evidence that information can indeed be processed, while at the same time it does not result in the required response. What can explain the absence of a response under these conditions?

3.2.1 Processing that is not sufficiently deep

Attention facilitates perceptual processes (Tipper & Weaver, 1998; Broadbent, 1958; Treisman, 1988) and allows higher-level cognitive processing (Cavanagh, 2004; Allport, 1993; Desimone & Duncan, 1995; Broadbent, 1958). Therefore, lack of attention or not paying 'enough' attention is a plausible explanation for 'the failure to apprehend'. The information is processed to some extent, but for some reason not enough attention is available to allow the type of processing that results in triggering the required response.

The attention argument has been used for explaining Change Blindness results (Rensink, O'Regan & Clark, 1997; Henderson & Hollingworth, 1999a, 2003a; Hollingworth, 2003; Hollingworth & Henderson, 2002; Hayhoe, Bensinger & Ballard, 1998; Pringle et al., 2001), claiming that paying attention to the specific features that change is necessary for successful change detection (Levin & Simons, 1997; O'Regan et al., 2000). The question here is whether attention facilitates selection (see Chapter 2) or whether attention facilitates more elaborate processing. Most plausible is that attention plays a role in both processes. Some argue that a change is not detected if the object is not the focus of attention at the moment that the change occurs (Rensink, 2000a), pointing to a failure to select the information. Others show that observers are well capable of detecting changes even when the object is not attended at the time of the change (Hollingworth, Williams & Henderson, 2001; Henderson & Hollingworth, 1999a, 1999b; 2003a; Hollingworth & Henderson, 2002; Hollingworth, 2003). This suggests that not-detecting the change does not necessarily have to be the result of a failure to select, but might rather be a problem of processing that is not deep and elaborate enough. In both accounts, attention plays a crucial role in detecting the change, but in this chapter we will only focus on the failure to respond and not on the failure to select.

Landman (2003) claims that even though the whole scene enters into iconic memory (which may be comparable to what Wickens (1984) calls the short term sensory store), only a small subset of items enters into the more stable working memory. This is the result the rapid decay of iconic memory. Iconic memory was first studied by Sperling (1960) and it is thought to be the literal visual memory that has a capacity of about 5 to 8 items and lasts for only tenths to hundreds of seconds (Allen, 1926; Avons & Phillips, 1980; Francis, 1996; Sperling, 1960; Dick, 1971). It is literal in the sense that it holds physical properties (e.g. the colour or size of letters) but no semantic properties (e.g., words vs. consonants). Working memory temporarily stores and processes information in order to perform a task (e.g. Baddeley, 1986, 2000, 2002; Jeffries, Lambon Ralph & Baddeley, 2004). Working memory therefore plays a crucial role in deeper processing of selected information. In case of 'the failure to apprehend' it may

be that information never entered working memory. Attention increases the chance of information entering into working memory, resulting in deeper processing of the information. This is in line with the claim of Landman (2003) that paying attention to items increases the chance of information entering into working memory, thereby increasing the chance of change detection. Working memory has a capacity limit of about 4 independent objects (e.g. Pylyshyn & Storm, 1988; Cowan, 2001), which is identical to the number of items people can monitor for a change (Pashler, 1988; Luck & Vogel, 1997).

That attention indeed results in deeper processing was shown by Liu and Jiang (2005). When observers were confronted with a brief presentation of 10 objects, they were only able to recognise at most one object out of a test screen containing 20 choice objects. Only one object was retained in working memory. In the control condition in which observers were allowed to look at the scene as long as they wanted, allowing more attention to be paid to every single item, more than 5 objects were remembered (with an average viewing time of 13 seconds). This limitation in memory is therefore likely to originate to a failure to encode visual details into working memory due to insufficient attention. This is in accordance with other findings (Melcher, 2001) showing that longer viewing times result in recalling more objects. Longer viewing times allow more objects to enter working memory.

These examples illustrate that attention and working memory play an important role in the depth of visual information processing. If an observer does not pay enough attention to selected information, the information does not or only partly enters working memory. This means that the information is not processed to a deeper extent in working memory. This failure to deeply process the information is one of the explanations for the failure to respond.

3.2.2 No need to respond

'The failure to apprehend' may also be the result of simply not seeing the need to respond. In these cases, the information is processed to such an extent that a response could be generated, but is simply not actively initiated by the observer.

Some evidence for this explanation is provided in the Pearson and Schaefer (2005) study, already briefly described in Chapter 2. They presented drivers with a photo change detection task, asking them to indicate any changes. By specifically in-structing one group of drivers that the results of the task would be used for future identification of drivers who need extra driver training, they emphasised the importance of providing the correct response. Participants that received this instruction were better at detecting driving-relevant changes than participants without this instruction. Interestingly, detecting changes for non-driving items

was not better for participants with this instruction compared to those without the instruction. This indicates that is was not the mere fact of paying more attention to the change detection task. However, the instruction may also have altered visual search and thereby selection.

Other illustrations of people not realising that they had to respond could be found in manipulations of central or marginal objects. Changes to semantically central items are detected faster than changes to other items (Rensink et al., 1997; Kelley et al., 2003; Landman, 2003; Pearson & Schaefer, 2005; O'Regan, Rensink & Clark, 1999; Rensink, O'Regan & Clark, 1997; Henderson, Weeks & Hollingworth, 1999), which may be explained by the fact that the observers simply did not feel the need to respond to changes of marginal items. Again here, it may also be due to the selection process, with central objects being selected more often than marginal objects. In driving scenes, participants are faster in detecting driving related changes than driving unrelated changes (Richard, Wright, Ee, Prime, Shimizu & Vavrik, 2002), which may point to the same issue.

The most direct evidence of people not realising they have to respond comes from Change Blindness studies. Some Change Blindness studies show the observer the change if they are not able to report it. In these cases, it may be that observers do not report a change but once pointed, they realise that they indeed detected this change without reporting it. We have already seen such an example in the Simons, Chabris, Schnur and Levin study (2002). Even though most participants did not report the change (disappearance of a basket-ball), twice as many people correctly reported the change if they were asked leading questions. This may be interpreted as the participants not realising this was what they had to respond to. A similar phenomenon was found in a real life experiment with an identity change of the experimenter. Levin, Simons, Angelone and Chabris (2002) found that some participants reported that they did not notice anything unusual, but once they were told that there was a person substitution, they indeed claimed to have detected this.

Under these circumstances it may very well be that the information was selected, entered the visual system, was processed but since participants did not realise it was relevant, the processing of this information did not lead to a response.

3.2.3 Failure in memory

If information enters the visual system and the information is processed to some degree, 'the failure to apprehend' may also be associated with a failure in memory. Indeed, it is feasible that the information was processed but immediately forgotten. By the time a response is required, the information may have vanished from memory. The question is why this information has disappeared from memory?

Wolfe (1999) introduced the term 'Inattentional Amnesia' instead of Inattentional Blindness, suggesting that the specific stimuli are indeed processed, but that in absence of attention they are simply not remembered (see also Rensink, 2000a, 2000b). In a series of experiments Horowitz and Wolfe (1998) demonstrated that participants did not retain information about previously viewed distractor items in a visual search task. In these studies, a target letter that had been a distractor in previous search trials was not found more rapidly than a target letter that was new to the search array. The lack of improvement in search efficiency suggested to Wolfe (1999) that attending to a distractor item on prior search trials did not establish a memory representation that could later be used to facilitate search for that item. In other words, the failure to report changes or to respond to objects may not reflect a failure in processing, but rather a failure of memory (Horowitz & Wolfe, 1998; Wolfe, 1999; Moore, 2001).

There are several hypotheses about the relationship between Change Blindness and memory. One hypothesis is that Change Blindness is the result of the replacement of the information about the first scene by information about the second scene. In other words: new visual information simply wipes out older information. Experiments on visual search and memory indicate that detailed representations do exist but that they are indeed replaced when a new stimulus is introduced (Becker, Pashler & Anstis, 2000; Rensink, 2000a; Landman, 2003; Liss, 1968; Sperling, 1967). Another hypothesis is that the first representation has faded by the time the second is presented. This hypothesis is based on experiments showing that the detailed representations that do exist rapidly disappear (Phillips & Singer, 1974; Stelmach et al., 1984). In Change Blindness studies, a blank screen is often used to separate the first from the second scene. The longer this interval between the presentation of the first scene and the second scene, the higher the levels of Change Blindness (Phillips & Singer, 1974; Rensink, O'Regan & Clark, 1997; Becker, Pashler & Anstis, 2000). This could be taken as evidence for the fading hypothesis.

Becker, Pashler and Anstis (2000) found that a cue, indicating the location of change improved change detection and identification as long as the cue was presented during the blank interval in between two displays. Since the cue only appeared after the presentation of the first display, all information from the first display was retained, otherwise the cue would not have had any effect. If the cue was introduced at the same time as the second display, there was no advantage for change detection. This supports the idea that it is not related to selection, since adding a cue at the time of the appearance of the second display would help selection of these items. Identification only improved with a cue when the time interval between the two displays was limited. The findings that cueing the location of a change during the

blank interval improves change detection and identification have also been found earlier (Averbach & Coriell, 1961; Gegenfurtner & Sperling, 1993; Sperling, 1960). These results suggest that there is an iconic memory for the first display (all items are selected) that persists during the blank interval. With the proper cue, information from this iconic image can be used to detect changes. The number of detected changes and identified items decreased with longer intervals, suggesting fading of the iconic representation. The fact that a cue appearing at the moment of presenting the second display did not improve performance (detection nor identification) supports the overwriting assumption. It is also plausible that the cue allows already selected information to be transferred to a more durable memory system by means of deeper processing, not subject to being overwritten by new visual information (Gegenfurtner & Sperling, 1993; Rensink et al., 1997).

Taken together, these results (Averbach & Coriell, 1961; Gegenfurtner & Sperling, 1993; Sperling, 1960; Becker, Pashler & Anstis, 2000; Rensink et al., 1997) suggest that there is indeed an iconic trace that is usually overwritten by new information. In these cases, 'the failure to apprehend' cannot result from a failure in selection, since adding a cue after presenting the first display improves change detection. This indicates that all information was retained before the display disappeared. However, directing attention to an item in this iconic trace transfers that item to a short-term memory buffer, with deeper processing of that information as a result. Once an item has been moved to this separate buffer it may be compared with the later occurring item in that location, leading to accurate change detection.

3.3 Explicit and implicit measures

Together these results clearly show that the link between information input on one side of the information processing cycle and response output on the other side is not a simple one. In order to understand the process of information intake, information processing and response selection, it should be realised that in addition to explicit measures that indicate that processing took place, there are also so-called implicit measures.

Explicit measures typically are those in which observers make an explicit manual or verbal response that particular information (a target) is present or absent. Examples of explicit measures would be to instruct observers beforehand to speak out loud whenever they see a specific item or to ask somewhere in the process if they have seen a specific item. Change Blindness often uses explicit reports, either asking observers to report a change when they see one, or afterwards ask observers whether they have seen anything strange. Problems arise when the failure to report a change is

used as evidence that observers were blind to the information. This is a problem that is similar to using verbal reports. Verbal reports, in which observers speak out loud while performing a task, assume that observers have a clear idea of the kind of information they need to report (Martens, 2000). As soon as they consider something to be irrelevant, it will not be reported, possibly leading to the claim that the information was not processed. Verbal reports may also omit information that participants use to perform a task (Ericsson & Simon, 1980). More automatic processes are generally not recorded in working memory and will therefore not be available for verbal reports. Nisbett and Wilson (1977) even warn that instructing people to verbalise specific information can even change cognitive processes and therefore task performance. Since verbalising takes more time than processing per se, participants process much more than they are able to verbalise (Martens, 2000). Also, people have the tendency to stop talking when they are under high workload or when they have to respond to something imminent (e.g. driver who has to brake to a braking lead vehicle).

Asking observers whether they have seen anything only after the information has been presented introduces three problems. The one already mentioned, is that the observer may have processed the information but did not consider it to be relevant. Because people think it is not relevant they do not respond or report it. The second already mentioned is failure of memory. It may be that information is processed but due to the time interval between processing and retrieval, the information is no longer available for retrieval and responding. In this respect, there is a positive relationship between traffic sign recall and the relevance of the information for the driver (Näätänen & Summala, 1976; Johansson & Rumar, 1966; Milosevic & Gajic, 1986). This is confirmed by Häkkinen (1965) who found that road signs with specific information, having a higher relevance for the task, were recalled more often than signs communicating more general information. Luoma (1991) found that information with a minor subjective importance suffers more from a time delay between the information presentation and recall than information with a high subjective importance. A third problem is that participants may fill out or generalise incomplete memories, leading to discrepancies between what people report afterwards and the behaviour they show when encountering the information (Ericsson & Simon, 1980).

Therefore, the key to explaining 'the failure to apprehend' lies in the definition of what is measured. Neurophysiological evidence (e.g. ERP signals), fixations, priming studies and forcing people to guess have all shown that much more is processed than explicit measures may lead us to believe. For this reason, a great deal of studies suggest that verbal reports are not always the best tool for measuring visual processing (Marcel, 1983a, 1983b; Graves & Jones, 1992; Kolb & Braun, 1995; Luck et al., 1996; McCormick, 1997; Moore & Egeth, 1997; Bar & Biederman, 1998; Chen, 1998; Dehaene et al., 1998; Mack & Rock, 1998). Implicit measures, such as eye fixations,

seem valuable in trying to explain 'the failure to apprehend', shedding new light on the visual processes involved (Rensink, 2000b; Fernandez-Duque & Thornton, 2000; Smilek et al., 2000).

The main advantage of eye movements is that under natural viewing conditions, without any specific instructions what to fixate, they provide an indication of what is being attended. As we have already seen, there is a strong relation between what is fixated and what is relevant for the task at hand and between what is fixated and what is being reported. Fixation duration and number of fixations have also shown to reveal the processing of information not necessarily revealed in explicit measures. Brain potentials may reveal that some information was actually processed, not available from explicit dependent measures. However, brain potentials are difficult to measure and interpret, since some brain potentials show a high correlation with explicit reports, being present in case of correctly reported changes and being absent when people are change blind or when there is no change (Turatto, Angrilli, Mazza, Umilta & Driver, 2002, Fernandez-Duque et al., 2000; Niedeggen et al., 2001). Also, some brain potentials are primarily related to variations in the confidence of the observer's judgments (Eimer & Mazza, 2005).

Another implicit measure for change detection is response time. In an experimental setting, observers had to respond whether a change was present or absent from one display to the next. Compared to the conditions in which a change was absent, observers needed more time to process the information in a display that contained a change. This was reflected in higher response times even though observers were not able to report the change (Williams & Simons, 2000; Mitroff, Simons & Franconeri, 2002). Forcing people to respond even though they cannot report a change or using paradigms in which the 'unreported' information is required for response on some later trials all reveal that explicit reports do not always represent an accurate measure of whether something was processed.

Of course the most important measure in this type of research is the response itself. If it is not important for the task that a response will follow, measuring a failure to explicitly report it is not so relevant. However, when a response is crucial, for instance in case that 'the failure to apprehend' results in an accident, the response to presented information is a crucial dependent measure.

Measuring the required response is very important in understanding the severity of the consequences. Consequently, explicit reports are only important if explicit reports are the required response for the task, e.g. when reporting information to another operator is of crucial information. Implicit measures are required when trying to understand the mechanism underlying 'the failure to apprehend'.
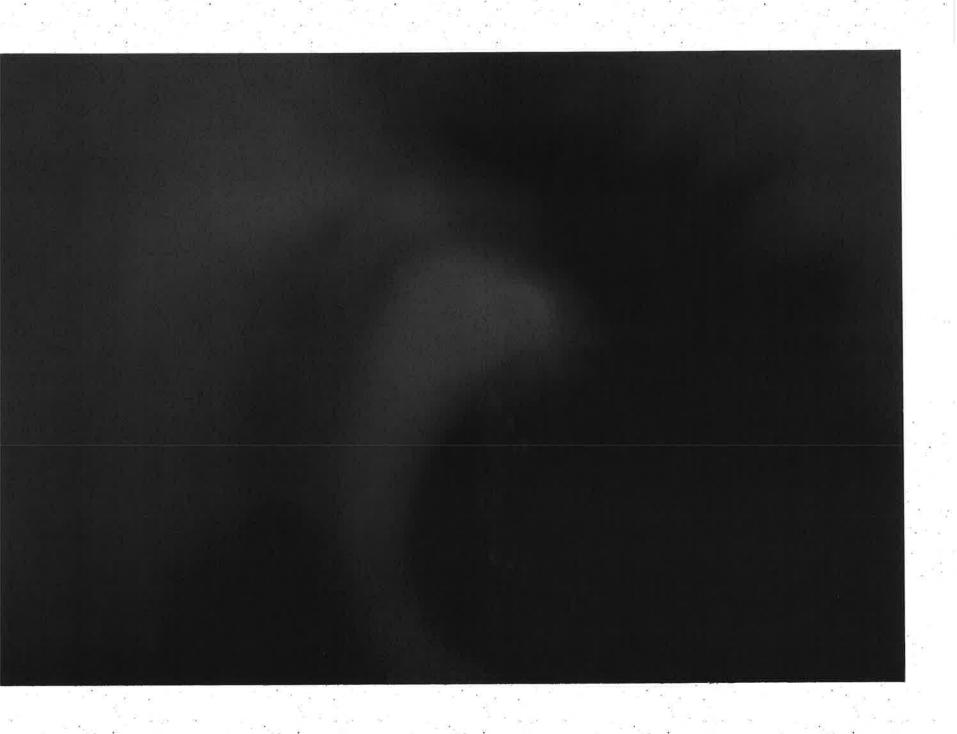
3.4 Conclusion

This chapter showed that selecting relevant information is not always sufficient to generate a response. There are various instances in which information is indeed selected, but there is still no response. This evidence comes from studies using explicit as well as implicit measures. Even if explicit measures (e.g. verbally responding that something is detected) do not reveal that anything was processed, implicit measures may show some level of processing. For example, fixation durations to a changed item have proven to be higher, even if observers do not explicitly respond to the change. Also, specific brain activity is found as a response to changes or new information without the observer being able to explicitly report the change. Some studies even showed that information that is not explicitly detected by an observer can be used in generating responses that require the processing of this information.

So what happens if this information is indeed selected and processed but does not generate a response? It may be the case that the information is indeed processed, but that the observer does not see the need to respond. In these cases, the information is processed to such an extent that a response could be generated, but the response is simply not actively initiated. This may indeed play a role if the observers are not aware that they have to respond or if responding to that item does not seem relevant for the task at hand. For the research theme of this thesis, this explanation is not viable since we specifically focus on information that is highly relevant for the task. Another explanation is that the information is selected, processed but is simply forgotten or overwritten by other information. Although this may be an interesting and important aspect of the failure to respond, is it not relevant for this thesis. In this thesis our main focus is on information that is visible at the moment that people need to respond. Since there is no time gap between the presentation of the information and the required response, there is no new information that has overwritten the original item and memory does not play a role. Yet another explanation is that the information is indeed processed, but this processing is not deep enough to generate the response. This insufficiently deep processing is most likely the result of insufficient attention for that item after it has been selected. In this respect it is also interesting that longer viewing times result in recalling more items, thereby revealing a relationship between viewing times and the depth of processing. In addition to the failure to select information (Chapter 2), the failure to deeply process relevant information seems to be an explanation that is relevant for the current research theme. Together, the failure to select and the failure to deeply process relevant information are viable explanations for 'the failure to apprehend'.

Given this analysis, the thesis focuses on visual selection of information, deeper processing of information, attention and the failure to respond. In order to get a better insight in the underlying mechanisms of 'the failure to apprehend', we need to

use implicit as well as explicit measures. By using eye tracking, we can see if people visually select the information relevant for the task. Glance duration is an indicator of the amount of information processing. Ultimately, an adequate response to the relevant information is a direct result of visual selection and deep processing.

4

Conditions that induce 'the failure to apprehend'

The previous chapters have illustrated that even though information may fall on the retina it does not always result in a response. In Chapter 2 we argued that a response is not given because the relevant information may not have been selected. In Chapter 3 we argued that even though the information may be selected and processed for some reason it did not result in a response. In the present chapter we examine the conditions under which 'the failure to apprehend' has been found. The underlying reason may be (1) failure to select as described in Chapter 2 or (2) failure to respond as described in Chapter 3.

4.1 Expectations

Observers can extract the gist of a scene from a single glimpse, that is within the first few hundred milliseconds of presentation (Biederman, Mezzanotte & Rabinowitz, 1982; Intraub, 1981; Loftus, 1983; Potter, 1975). This ability helps people to rapidly understand their surroundings (Biederman, Rabinowitz, Glass & Stacy, 1974; Intraub, 1980, 1981; Potter, 1976; Potter & Levy, 1969). The gist of a scene evokes a 'scene schema'; a general cognitive structure that helps to organise perceptual information (e.g. Bartlett, 1932; Coren, Ward & Enns, 1994; Rumelhart, 1976). People use these schemata to structure their world (Schank & Abelson, 1977). Schemata help to interpret new information by activating expectations about what things look like, how they behave (Taylor & Crocker, 1981), what type of objects are present in a scene, and how they are spatially related (Biederman, 1981; Biederman, Mezzanotte & Rabinowitz, 1982; Hollingworth & Henderson, 1998). It is by means of these expectations that schemata guide information selection and processing. Typically, schemata are developed through repeated exposure or experience with specific events or situations (Fiske & Taylor, 1991; Mandler, 1979). Through repeated encounters, people learn what information is most important and they allocate their attention accordingly.

The activation of a scene schema facilitates the perceptual analysis of schema-consistent objects. It is easier for people to identify objects that are consistent with the scene context than to identify non-consistent objects (Biederman, Mezzanotte & Rabinowitz, 1982; Boyce, Pollatsek & Rayner, 1989; Boyce & Pollatsek, 1992; De Graef, 1992; Henderson, 1992b; Rayner & Pollatsek, 1992; Antes & Penland, 1981; Biederman, Mezzanotte, Rabinowitz, Francolini & Plude, 1981; Friedman, 1979). The main mechanism underlying this enhancement is assumed to be the activation of a scene-specific schema (Friedman, 1979).

In most cases, scene schemata facilitate scene perception and allow quick interpretations of information. However, activated scene schemata may also have negative consequences. People may remember items that were actually not there, just because the general schema was activated and people expect them to be present.

Alternatively, the schematic map may override stimulus data that conflict with the map expectations (Gale & Findlay, 1983). These phenomena have been demonstrated in various studies (Neider & Zelinsky, 2006; Theeuwes, 1991c, 1992c; Sarter & Woods, 2000; Meyers & Rhoades, 1978) and this is presumably what happens in case of Change Blindness and Inattention Blindness. The Meyers and Rhoades study (1978) showed the effect of expectations on the way that people scan their surroundings. When searching for information, people first search at the likely locations, with search for an object at a non-predictable location being much slower than search for an object at a likely location. This is a typical example of schemata that have developed through repeated encounters, since people have learned where to find specific objects in a specific environment. The same holds for the Theeuwes study (1991c). Road users have learned that traffic signs are located on the right side of the road. Showing road scenes activates the schema with road scene expectations, with observers claiming that no traffic sign was present if it was located at an unexpected location. Even when observers learned that the expected location was not always an adequate cue for responding they did not adjust their search strategy, showing the strength of expectations. The search strategies remained the same even in conditions in which the target object was consistently presented at unlikely positions. Observers tended to search at the most likely locations, sometimes resulting in a 'No' answer if the target was not found in this place. In a dynamic visual search task, Theeuwes (1992c) investigated the balance between top-down visual search, ruled by expectations and bottom-up search, ruled by object properties. Participants watched a video of an approach of an intersection while searching for a specific traffic sign that was again located at either an expected or an unexpected location. Again, the results showed that eye movements were first directed to the locations where traffic signs were expected, leading to a delay in response time for targets at unexpected locations. The strength of these expectations was demonstrated by the fact that the presence of a distracting traffic sign or a pedestrian hardly affected this search pattern.

Also, the example of Sarter and Woods (1997) showed that incorrect expectations may lead to 'the failure to apprehend'. In the cockpit of a highly automated aircraft, pilots failed to respond to changes in automation configuration especially when the automation took an unexpected action or when it completely failed. Since this was not expected, it did not lead to a response. Pilots also reported that they looked where they expected to find changes which may explain the results in line of failure to select. If pilots only fixate where they expect to find changes, then there is the risk of not selecting important yet unexpected information. The fact that pilots do not always monitor or respond to unanticipated changes in automation settings has been replicated in other studies (Huettig, Anders & Tautz, 1999; Sarter, Mumaw & Wickens, 2007).

In many Change Blindness studies, 'the failure to apprehend' occurs in situations in which observers have expectations about the scene. Basically, there are two types of Change Blindness studies. One type specifically asks observers to look for a change from one picture to the next. The other type introduces a change without the observer expecting a change. For the first type, one can argue that the types of changes one has to look for are unexpected. For the second type one can even argue that a change itself was not expected. Typically, people are not replaced during a conversation, nor do buildings change location or size from one instant to the next. A 25% enlargement of a prominent building on a photograph (Grimes, 1996) is not to be expected, even if one knows a change may occur. Even in movies in which observers are not familiar with the actor or the props, it may not be so surprising after all that changes made from one shot to the next are not detected. People do not expect objects to be replaced from one moment to the next (Simons, 1996; Levin & Simons, 1997) nor do they expect an actor to be replaced by another actor partly wearing the same clothes (Levin & Simons, 1997). In natural settings, objects do not suddenly disappear (Simons et al., 2000) nor are people that we speak to (Simons & Levin, 1998) or that we try to photograph (Levin, Simons, Angelone & Chabris, 2002) replaced by someone else. Since observers do not expect a change, they may not actively search for one. Simons and Mitroff (2001) claim that when observers are not actively searching for a change they tend to focus on the meaning of a scene, which is important for their immediate actions and goals. Providing a stranger with directions continues if stranger 2 replaces stranger 1. Following a discussion between two people in a movie is still possible if a scarf changes colour. This is confirmed by the fact that observers are more likely to perceive probable changes than improbable changes (Beck, Angelone & Levin, 2004).

In case of Inattentional Blindness studies, observers do not have to respond to a change. It is not the change that is important, it is the presence of the information in itself that requires a response. Normally, when commercial pilots prepare for descent, they check various instruments. However, it is the job of the air traffic controller to make sure that the runway is empty. So even though pilots would need to respond to an airplane on their runway, they normally do not encounter other airplanes on their runway blocking their path. This makes the event highly unexpected. Also the look-but-fail-to-see accidents happen in situations with strong expectations. In most of the cases, other road users at intersections are car drivers. Because car drivers are the most expected other road users, people may fail to select or respond to the presence of motorcycles or cycles, since their presence is not expected (a.o. Rumar, 1990; Herslund & Jørgensen, 2003). This explanation for the look-but-fail-to-see accidents is only a speculation and is not based on empirical evidence. In the example of the nurse looking at the label of the drug, she did not realise it was the wrong drug possibly because she expected to have taken the right drug and only checked the label to confirm that she was right, ignoring any contradictory information.

The strong role of expectations is also found in the SEEV model developed by Wickens and colleagues (Wickens, Helleberg, Goh, Xu & Horrey, 2001; Wickens, Goh, Helleberg, Horrey & Talleur, 2003; Horrey, Wickens, and Consalus, in press). The SEEV model predicts how observers allocate their visual attention to different areas of interest in various operational environments such as in an airplane or a vehicle. According to the model, visual scanning aims to bring task-critical information into foveal vision. Visual scanning is thought to be affected by four factors: Salience, Effort, Expectancy and Value. The more salient an object, the higher the change that this object will be selected (see also 2.3.1). Effort is an inhibitory component that discourages observers from scanning between two locations that are located far apart. Expectancy characterises the tendency for observers to look where they expect to find task-relevant information. Value refers to the the fact that observers tend to sample information sources that are relevant for the task. According to the model salience and effort are bottom-up in origin; expectancy and value are considered to be top-down. The model is limited to foveal vision only, and applies to 'the failure to select' (Chapter 2) and not to 'the failure to respond' (Chapter 3).

In summary, strong expectations may induce the phenomenon 'the failure to apprehend'. In this respect, expectations may play a role in two ways. On the one hand, it may be that people only select information that is consistent with their expectations. This implies that in case of incorrect expectations, the information is never selected, a mechanism that was described in Chapter 2. This is what happens when observers only search for specific information at expected locations, and decide that the information is not present whereas it is in fact present, but at an unexpected location. On the other hand, even when the relevant information is selected, expectations may still induce 'the failure to apprehend'. It may be that information is selected and is processed to some extent but since it does not fit the activated schema (not expected), people need more time and more attention to deeply process the information. In this case we assume that only with deep and elaborate process-ing, information that is inconsistent with the expectations may result in an adequate response. This process was discussed in Chapter 3.

4.2 Automaticity

'The failure to apprehend' also occurs often in situations in which there is some degree of automaticity in task performance. Automaticity occurs when people are highly skilled in performing a specific task, with more or less automatic stimulus processing that may not enter awareness (Tzelgov, 2000; Saylor & Baldwin, 2004). Automatic performance develops if a specific task is trained over and over again.

The concept of automatic performance has been described in many theoretical frame-works (e.g. Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Hasher & Zacks,

1979; Posner, 1978). Automatic performance is described as fairly resource-free, fast and parallel, not limited by short term memory capacity, not under the direct control, not entering awareness, and showing high transfer to similar tasks (e.g. Rasmussen, 1986; Fitts & Posner, 1967; Shiffrin & Schneider, 1977). A process is labeled as 'automatic' if it has acquired the ability to run without monitoring (Tzelgov, 1997) or is unavailable for conscious awareness (Marcel, 1983a). In automatic performance, a visual stimulus automatically generates a response, without any top-down control. An example of automatic processing is word recognition (MacLeod, 1991; Deutsch & Deutsch, 1963). Studies show that words are recognised at a subconscious level even when people actively try to ignore words (Lewis, 1970; Tipper & Driver, 1988). This is clearly shown in the Stroop test (Stroop, 1935). In this test, words are written in different colours. The task for observers is to name the colour of the ink in which the word is written. If the word is written in green ink, they are supposed to say 'green'. However, the words are the names of colours. So for instance the word Blue could be written in green ink and the participant is supposed to say 'green'. The task shows that people read words automatically whereas naming colours is not done automatically. In the example just given, people will say 'blue' more easily instead of the right answer 'green'. The Stroop effect emphasises the interference that automatic stimulus-response links have on more mentally effortful task. Automatic performance is mostly the result of well-developed skilled behaviour (Schneider, Dumais & Shiffrin, 1984), resulting from abundant practice (Rasmussen, 1986).

In their classic study, Shiffrin and Schneider (1977) investigated the phenomenon of automatic visual search behaviour. The researchers specifically looked at the difference between learning to find relevant items with constant stimulus-response mapping (same stimulus always leads to the same response over trials) and with varied stimulus-response mapping (e.g. stimulus A was the target one some trials but a distractor on other trials). They found that after practice with constant mapping, automatic stimulus detection occurred: detection took place without requiring attentional capacity or intentional control. Shiffrin, Dumais and Schneider (1981) and Fisk, Lee and Rogers (1991) conducted experiments in which either the target or the distractor set was changed following an extensive training period. In both studies, strong positive transfer was observed when either the target set or the distractor set was maintained, which indicates automatic search behaviour. The amount of transfer that occurred when the distractor set was maintained was equivalent to when the target set was maintained. The latter finding suggests that with practice not only perception of the targets but also perception of the distractors becomes automatic. If the role of either the target or the distractor set is changed people have to consciously switch back to the use of controlled search (Fisk, Lee & Rogers, 1991; Shiffrin, Dumais & Schneider, 1981). But even then, automatic performance is so strong that prior target or distractor sets still interfere (Shiffrin & Schneider, 1977).

How do these findings relate to 'the failure to apprehend'? In case of automatic task performance, there is a direct link between a visual stimulus and a response. This means that there is no top-down control over what type of stimulus will result in what type of response. This means that in highly practised tasks, 'the failure to apprehend' may be the direct result of information directly triggering incorrect behaviour (incorrect response or incorrectly refraining from responding). Consider the example of the Stroop test. Even though an observer wants to name the colour of the word, he automatically names the word itself. When the information is selected it triggers the automated response, even though in this case it should have resulted in another response. However, 'the failure to apprehend' in automatic tasks may also result from the failure to select. In automatic tasks, visual search is not actively directed by the observer (Norman & Bobrow, 1975), but rather bottom-up or data-driven (directed by objects in the environment that ask for attention). If the information that requires a response does not have sufficiently strong bottom-up features, it may not be selected for further processing. Most plausible is that the information is selected, but the visual information automatically triggers a response that is incorrect. It may also be the case that the visual information is so similar to other information that normally triggers an automatic response that even though it is slightly different, it still triggers the automatic (in this example incorrect) response.

Sometimes task performance according to schemata is incorrectly referred to as automatic task performance. For instance, Gibson and Crooks (1938) describe walking as an activity that is learned by means of controlled performance, but after sufficient practice, walking is performed in an automatic way without conscious control. Even though the physical action of walking is automatic, walking to the neighborhood bakery on corner of the street, thereby crossing some side streets, is a task that is performed according to schemata. Based on prior experience of walking to the bakery, the pedestrian developed schemata of where important information is, where to look (left and right before crossing the side streets) and how to behave. Even though it is true that automatic task performance is stereotyped and inflexible (Fitts & Posner, 1967; McLeod, McLaughlin & Nimmo-Smith, 1985; Naveh-Benjamin & Jonides, 1986; Johnston & Dark, 1986), which to some extent also holds for the schemata, there is a clear difference. With automatic task performance (the physical action of walking), there is a direct link between the stimulus and the response, without any top-down control. In case of schemata, there is a strong top-down control (making a daily walk to the bakery).

Automatic performance or automatic information processing may interfere with adequate performance if the required response is different from the one that was trained or done many times before. This way, two processes may account for 'the failure to apprehend' in case of automatic performance. Automatic search behaviour

selects information belonging to this automatised task. This means that information that is not part of this automatic task is not selected and can therefore not result in a response. Also, automaticity may result in the erroneous selection of stimuli that are not part of the current task set. When a task is automated, the context in which people are placed will automatically generate a behavioural repertoire that may be inappropriate. For example, driving in the UK with a rental car while being used to a left hand steering wheel generates behaviour that is not appropriate when driving in the UK (e.g. trying to shift gear with your right hand). Most likely, 'the failure to apprehend' in the context of strong automatisation of tasks has nothing to do with the notion of selection but rather to the failure to respond as described in Chapter 3.

4.3 Vigilance

A third situation in which 'the failure to apprehend' is found is in case of tasks involving vigilance. Vigilance tasks require sustained attention, being prolonged and continuous (Jerison, 1970; Warm, 1977). These tasks typically result in low task load (Jerison, 1970; Warm, 1977) or induce a low level of arousal (Parasuraman, 1984). During vigilance tasks, observers monitor targets that occur infrequently and the targets are clearly perceivable when the observer is alerted to them. Examples of typical vigilance tasks are inspecting individual items for classification of manufactured goods or radar monitoring in an air traffic control centre (Wiener, 1984). The challenge for the operators is to maintain some level of alertness despite the low task load (Jerison, 1977).

The onset of vigilance research was during World War II. Operators were found to miss crucial information after hours of watching a radar screen despite the fact that the targets were of high importance to national safety. This lead to various studies trying to understand what happened. The most famous classical vigilance test is the Mackworth clock test, in which observers were asked to detect a double jump of a pointer along the circumference of a clock display, that normally only jumped one step every second. Mackworth (1948) showed that in operational settings like these, the quality of sustained attention deteriorates rapidly over time. What was considered to be shocking in those days was the fact that observers missed targets even when visually fixating them (Baker, 1960; Mackworth, Kaplan & Metlay, 1964). The more time observers spent on this task, the more performance declined. This progressive decline in performance with low task load has been called the decrement function (Dember & Warm, 1979) or the vigilance decrement (Davies & Parasuraman, 1982).

The commander of the submarine not responding to the presence of a fishing vessel even though he was looking through the periscope fits this picture. He was probably on duty for some time, without any events happening. This risk of not

responding to important information may also play a role in operator tasks in which operators have to monitor many screens during longer periods of time. In many of those tasks, the events that actually require a response are very rare. In this respect, the Signal Detection Theory is relevant. This theory, first introduced by Green and Swets (1966), describes the relationship between the presence of targets and distractors and the decision of an observer about whether something is a signal (target) or noise (distractor). The Signal Detection Theory treats the decision maker as an active decision maker who makes difficult perceptual judgements under conditions of uncertainty. In this respect, the observer can make four types of decisions: 1) the stimulus is present and the observers thinks it is absent (which is called a miss) 2) the stimulus is present and the observer thinks it is indeed present (hit) 3) the stimulus is absent and the observer thinks it is indeed absent (correct rejection) and 4) the stimulus is absent and the observer thinks it is present (false alarm). In case of 'the failure to apprehend', we are referring to category 1 (miss). In the Signal Detection Theory, observers also have a specific response bias, or criterion. An observer may be prone to say 'yes', using a liberal criterion, resulting in many hits but also in many false alarms. An observer with a conservative criterion says 'no' most of the time, resulting in a low level of false alarms but also in many misses. Since in vigilance tasks, there is an extremely low number of items that require a response, observers are biased towards a very conservative criterion, resulting in more misses, or in our terminology 'the failure to apprehend'.

Vigilance does not fit most Change Blindness situations. In most Change Blindness studies, participants are asked to respond to changes with many changes being present. Also, the task is often very limited in time (no performance over longer periods of time) and task load is not that low. However, Inattentional Blindness studies may fit vigilance like situations, especially in real life settings of long shifts in which events that require a response are rare.

Several neurological models claim that the quality of vigilance performance can be explained by the level of arousal (Hebb, 1955; Sharpless & Jasper, 1956; Frankmann & Adams, 1962). These approaches indicate there is an optimal level of arousal associated with optimal performance. Impairments in performance in vigilance tasks are produced by a decrease in arousal, arguably because of low task load. The concept of arousal has been described by several authors (e.g. Hebb, 1955; Duffy, 1957; Yerkes & Dodson, 1908).

In conclusion, 'the failure to apprehend' may occur in vigilance tasks. The characteristic of vigilance tasks is that there is some sort of monitoring, in which events that require a response are very rare. Under normal vigilance situations, task load and arousal level are low since the events that require a response are rare. Because of

this low task load, it will be difficult for the observer to remain vigilant and keep a sufficient level of sustained attention. Change Blindness tasks do not really fit the concept of vigilance task, but some Inattentional Blindness tasks do. One way to explain 'the failure to apprehend' in vigilance tasks is by the concept of attention. Because of the low level of attention, information may not be selected for further processing or the processing may not be to such an extent that it allows the proper response. Another explanation may be a conservative decision criterion that observers use. Since targets only occur very infrequently, the observer has set a conservative criterion for responding. A conservative criterion will result in high miss rates, or so to say 'the failure to apprehend'. In that respect, misses are not so much related to the failure to select, as described in Chapter 2. In many vigilance tasks, the observer has to decide 'yes' (target) or 'no'(distractor) for one stimulus at a time. Typical examples are the Mackworth clock test or an observer who has to inspect individual items on an assembly line. In these cases it is plausible that the individual items are selected. In these cases, 'the failure to apprehend' is more related to the depth of information processing. Since the number of targets is low, attention paid to the processing of every individual item is low and therefore deeper processing is limited.

4.4 High task load

Task load is said to be high if it demands a lot of processing resources (Navon & Gopher, 1979). While some tasks are easy to combine, others compete for resources (Wickens, 1984, 2002). This competition is referred to as high task load. Such competition between tasks or task elements is an intrinsic characteristic of combining tasks (or task elements) and cannot be easily modified by simply adopting a different strategy. Attention theories assume that there is a limited pool of attentional resources (also called 'capacity' or 'effort') that can be distributed across tasks (e.g. Kahneman, 1973; Norman & Bobrow, 1975; Navon & Gopher, 1979; Wickens, 1980, 1984; Kerr, 1973; Shiffrin, 1976). This basically illustrates the problem; since attentional resources are limited it may be that the proper information is not selected for further processing or that processing is not deep enough. In case of high workload and stress, operators fail to process information that is contradictory or inconsistent with their own expectations (Sheridan, 1981), suggesting that in case of high workload, people depend even more on expectations.

Considerable research is devoted to studying performance trade-offs between tasks or task elements as task demands vary (e.g. Navon & Gopher, 1979; Parasuraman, Molloy & Singh, 1993). Parasuraman, Molloy and Singh (1993) had observers perform tracking and fuel management tasks under simulated flying conditions, while they also had to monitor an automated engine status task. More than 72% of the malfunctions on the engine status task were detected while carrying out tracking and fuel

management. When participants only performed the monitoring task without the tracking and fuel management tasks, more than 95% of the failures were detected. This was taken as evidence that human monitoring suffers when performing other tasks simultaneously. The experimental setting used is related to Inattentional Blindness.

High task load is said to transfer into overload when performance starts to decline. This is also called 'selective attention deficit' (Schneider & Shiffrin, 1977). By paying attention to one part of the task, another task or task elements will receive too little attention, which relates overload or high task load to the concept of distraction. The example of the pilot crew being utterly concerned with the flashing bulb on the control panel can be explained by the team allocating all attention resources to this problem. The experienced task load by the first alarm therefore lead to the failure to select other crucial information, resulting in the plane crash.

As mentioned before, high task load also relates to distraction, with different task elements competing for attention. The result of distraction is an impaired capacity to process relevant information (Rumar, 1990). Recarte and Nunes (2003) studied whether adding mental tasks (thereby increasing workload) affects visual-detection and response-selection capacities. Similar to their earlier experiments, Recarte and Nunes (2000) found that mental tasks resulted in less variability in the horizontal and vertical gaze positions, so in a reduced glance activity. In a driving study they found that performing secondary tasks reduced the inspection of the mirror and the speedometer. This study shows that increased workload resulting from mental tasks produced endogenous distraction, decreasing the capacity to process visual stimuli. When performing mental tasks, the percentages of detected targets (flashing spotlights) and/or correct responses decreased significantly. They concluded that a general interference effect was produced by assigning attentional resources to the mental tasks (distraction) rather than to detecting the targets, with a reduced visual inspection window as a result. Secondary tasks that were rated as 'easy' did not affect spatial gaze concentration or visual search behaviour. This was confirmed in a series of experiments by Braun (Braun 2001, 1994; Braun & Julesz, 1998; Lee, Koch & Braun, 1999). The experiments showed that introducing an additional task, thereby increasing the task load, deteriorated performance on the main task. Performance on the additional task and performance on detecting the critical stimuli were strongly negatively correlated, indicating that the performance gain in one task is lost to a performance decrease in the other task. Many other studies have demonstrated similar effects, showing examples of what we call 'the failure to apprehend' when observers are simultaneously engaged in some other task (for reviews, see Holender, 1986; Simons & Chabris, 1999). Additional tasks, such as the Working Memory Span Test (Baddeley et al., 1985) and a phone conversation, are found to

decrease change detection in driving-related Change Blindness paradigms (Richard et al., 2002; McCarley, Vais, Pringle, Kramer, Irwin & Strayer, 2004).

An increase in difficulty of one task can give impairment of performance on another task. If a task requires a lot of attentional resources or when a task is visually demanding, it is necessary to engage in some sort of sequential (visual) sampling. Measuring these sequential (visual) sampling strategies is a valuable way of assessing time sharing aspects and getting a grip on what is attended and what is not. Tasks in which these sampling strategies play a role are for example flying an aircraft or scanning a nuclear power instrument panel (Moray, 1986). When the task load is too high, more tasks or task elements need to be attended than allowed by the available attentional resources. Older drivers, who are known to have specific attentional problems, have found to be more prone to Change Blindness in driving related changes than younger drivers (Caird, Edwards, Creaser & Horrey, 2005; McCarley et al., 2004; Pringle, Irwin, Kramer & Atchley, 2001).

Altogether the results that are found in studies dealing with task sharing or high task load seem to point towards 'the failure to apprehend' resulting from failure to select visual information. As we have seen, people tend to focus only on a small portion of all visual information available when task load is high. It seems that only specific information that observers consider to be relevant is selected, thereby ruling out other information. This phenomenon, also called selective attention deficit, has been found in operator tasks, pilots and car drivers. In this respect it is interesting that even mental tasks, that do not require the eyes to be fixated at specific visual information, result in reduced active scanning patterns. So even mental tasks that do not require visual input take resources away which may result in the failure to select the relevant visual information.
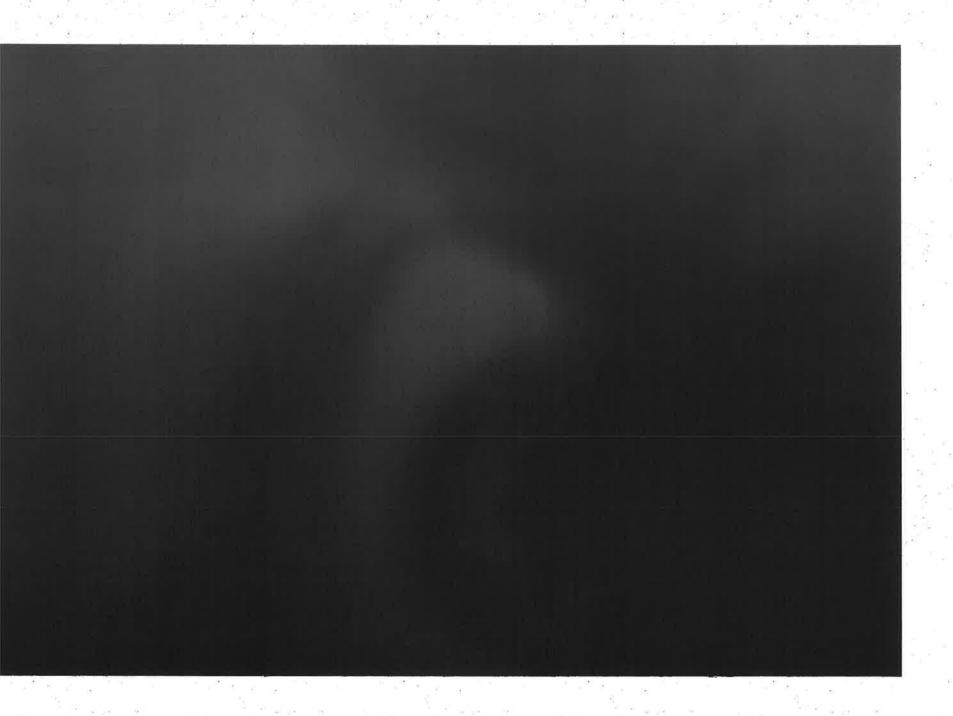
4.5 Conclusion

There are four situations in which 'the failure to apprehend' may occur; in case of strong expectations, in case of automatic tasks, in case of vigilance tasks and in conditions of high task load.
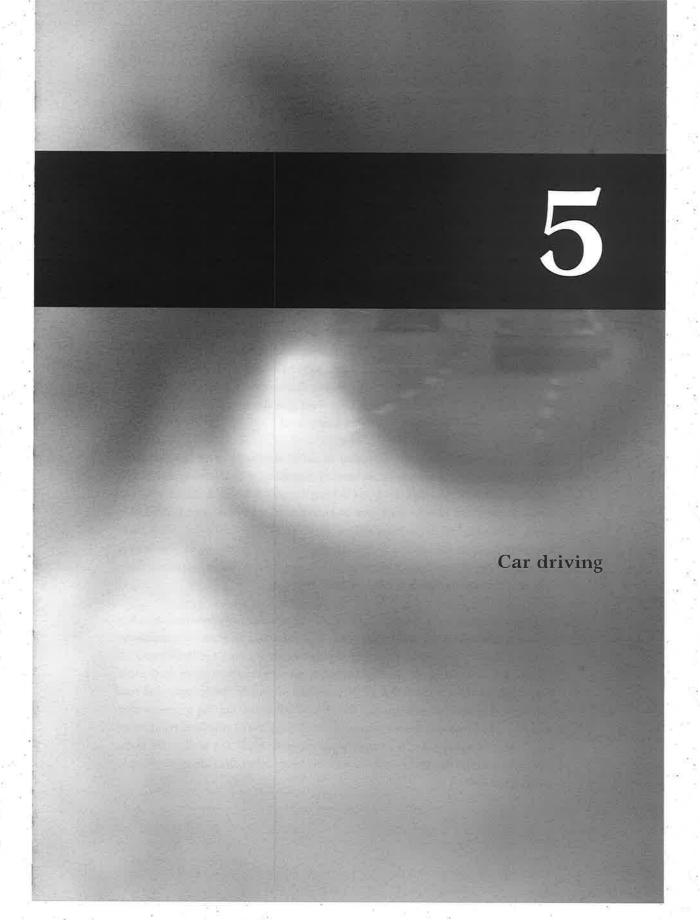
In case of strong expectations, observers use schemata to scan and interpret their world. The schema guides visual search and attention by means of top-down control. The schema prioritises the selection and identification of objects that are consistent with the scene context. 'The failure to apprehend' in case of expectations and activated schemata may both result from the failure to select and the failure to respond. In this respect, there is a strict difference between performing a task according to schemata and automatic task performance. In case of automatic task performance, there is a

direct link between a stimulus and a response, without much room for top-down control. In this case, there are two explanations for 'the failure to apprehend'. It may be that the information is not selected and therefore the information cannot trigger the automatic response. The other option is that the information is indeed selected, but that the information automatically triggers the response whereas in this case it requires a different response.

In vigilance tasks in which an observer inspects (and therefore selects) individual items or events and decides whether a response should be given or not, 'the failure to apprehend' has to be the result of the failure to respond. The failure to respond is either the result of a conservative decision criterion due to the low occurrence of targets or due to the low level of arousal and/or attention. Because of sustained attention, the arousal and attention level of the observer may be so low that the level of processing is not sufficient to generate a response.

In case of high task load or task sharing, the phenomenon of 'the failure to apprehend' is likely to result from the failure to select. Since people only have a limited amount of attentional resources, not all task elements receive attention. In this respect we can also speak about distraction, with some information distracting the eyes away from other information. Even in case of mental tasks, people reduce the activity of their scanning patters and have the tendency to fixate a limited proportion of all information available. We therefore conclude that high workload may result in 'the failure to apprehend' since it avoids the information from being selected.

5

Car driving

The present thesis addresses the topic of 'the failure to apprehend'. In the previous chapters we discussed potential underlying mechanisms for 'the failure to apprehend', such as a failure to select (Chapter 2) and a failure to respond (Chapter 3). In Chapter 4 we discussed four situations that are often associated with the occurrence of 'the failure to apprehend'.

In addition, this thesis focuses on driving to demonstrate the effects of 'the failure to apprehend' in daily life. This chapter discusses 'the failure to apprehend' in the particular context of driving, using Rasmussen's three stage task performance model (Rasmussen, 1986) as a basis. To explain the underlying causes of 'the failure to apprehend' at each of the three task performance levels of Rasmussen, we propose an elaboration of the original model.

The driving task is often analysed in terms of the three different performance levels distinguished by Rasmussen (1986). Although Rasmussen's model is a general task performance model, applicable to different sorts of tasks, it fits the driving task well (e.g. Hoedemaeker, 1999; Kuge, Yamamura, Shimoyama & Liu, 1998; Hollnagel, Nåbo & Lau, 2003). The three levels of behaviour that Rasmussen distinguishes are the knowledge-based, rule-based and skill-based level.

1. Knowledge-based behaviour is applied in novel situations or at new locations and it represents a more advanced level of reasoning. It is the most demanding level of the three. An example in the driving context is a novice driver who still has to think about how to shift gear or an experienced driver who is driving in a city centre he has never been before. With knowledge-based behaviour, new knowledge has to be applied to the situation at every moment, so it is a very conscious way of handling information and responding to that information. Since it is very demanding, there is a risk of task overload.

2. Rule-based behaviour is characterised by the use of rules and procedures to select a course of action in a familiar situation. The rules can be a set of instructions, e.g. if..... than...., acquired by a person through experience or provided by another person. An example in the driving context is giving priority to other road users, where drivers have learned that in the presence of specific traffic signs and road markings they have to give priority. Rule-based behaviour applies to interpreting everyday situations and scenarios as well as applying traffic rules and regulations. Problems at the rule-based level may occur if people apply the wrong rule to the situation or misinterpret the situation and therefore select the rule that applies to another situation.

3. Skill-based behaviour represents a type of behaviour that requires very little attention and does not allow conscious control to perform or execute an action. Skill-based performance is highly related to automatic task performance. An example is an experienced driver steering the car between the road markings. The driver does not have to think about his task and small deviations in lateral position automatically trigger a steering response. Skill-based behaviour is shown when a task is highly trained.

When applying this model to the driving task, it is not possible to take a subtask (steering, shifting gear, braking, etc.) and exclusively fit it to one single level. Where the subtask 'shifting gear' is at the knowledge-based level for a novice driver, it is skill-based for an experienced driver. Since the full description of skill-based, rule-based and knowledge-based behaviour applies to experienced drivers only, we focus on experienced drivers.

As discussed in Chapter 4, the four situations in which 'the failure to apprehend' is most likely to occur are; situations in which people have strong expectations, situations in which people show automatic task performance, situations that induce vigilance, and situations that have a high task load. We will now illustrate these situations on the basis of Rasmussen's model.

5.1 Skill-based and automatic task performance

Skill-based behaviour corresponds best to what we refer to as automatic task performance. In case of automatic performance, there is a direct link between presented information and the response. Information is processed completely bottom-up, with information directly triggering a response. In case of automatic task performance, there is not much room for top-down control.

An example in the driving context is lane keeping. An experienced driver has practised the task of lane keeping so often that he performs this task at an automatic level. Getting too close to a road marking on the right side automatically triggers a steering response to the left. This is done without any top-down control. Godthelp (1988) found that car drivers make corrective steering actions at a constant Time-to-Line Crossing (TLC) irrespective of vehicle speed. TLC represents the time it takes, with unchanged heading and speed, before a car will reach the lane boundary or road marking. Apparently, the driver uses the TLC as a safety margin. If a certain minimum TLC value is reached, a corrective steering action is automatically triggered.

This was confirmed by Van Winsum and Godthelp (1996) in negotiating curves. The TLC minima to the inner lane boundary were constant over different curve radii. Normally, this completely bottom-up way of processing is very efficient and lane keeping is done in a safe way without occupying many attentional resources. Another example is braking in response to activated braking lights from a lead vehicle. This response is automatic that there is no top-down control. As soon as a car in front brakes very abruptly, the driver automatically releases the gas pedal and brakes. It is almost impossible to ignore the red braking lights of a lead vehicle and not hit the brake. This automatic link is strong and guarantees a fast response.

Although automatic performance does have its advantages (response is fast and does not require many attentional resources), there are also problems associated with an automatic response. The presentation of information that automatically triggers a response is so strong that all other information will be ignored. There is hardly any room for top-down control in automatic task performance. That means that it is almost impossible to affect the response by the driver. This may lead to 'the failure to apprehend' in driving. Again, consider the example of lane keeping. Under normal circumstances, this automatic task performance leads to safe behaviour, that is keeping the car in between the road markings. However, in case of road works, accidents may arise due to this automatic response without any top-down control. For example in the Netherlands, in situations in which there are road works, drivers have to attend to the yellow (temporary) road markings and ignore the regular white markings. This task is very difficult to perform since the presence of road marking (regardless of its colour) will trigger automatic lane keeping. What typically is observed in road works situations in the Netherlands is that drivers start to drive in between one white and one yellow line. Even though drivers may know that they should only attend to the yellow lines, there is no cognitive control that allows them to selectively respond to the yellow lines. In other words, they cannot help it that they respond to the two lines that are closest to the vehicle. Obviously, the result of this is that drivers try to negotiate the vehicle within the boundary of a much too narrow lane, which increases task load. In case that a driver automatically follows the white markings instead of the yellow ones, this may even cause side collisions since this will result in two drivers driving too close together. Following the white road marking may even lead to a direct collision with for instance a barrier. There have been real accidents from road users following the track of the old road marking, thereby colliding with a road work barrier. Because of these types of accidents in road work situations, it is more and more common to actually erase the white markings when the new yellow lines are introduced. By erasing the white road markings, 'the failure to apprehend' in automatic task performance is avoided since it takes away the information that automatically triggers the (in this case incorrect) response. It is not

always sufficiently checked if there are any misleading road markings that may lead to dangerous situations.

Another example of accidents resulting from automatic responses is the case of responding to a braking vehicle in front. As an automatic response, the bright red braking lights from the car in front may lead to a road user hitting the brake fully. This response is so automatic that experienced drivers do this even if it were better to steer to the right to avoid the object in front. Even though any driver knows that fully hitting the brake may cause the wheels to lock, possibly resulting in a collision, it is almost impossible not to perform this action. Since this response is known to be fully automatic without much top-down control, anti-lock braking systems (ABS) were invented.

5.2 Rule-based behaviour and schemata

Rule-based behaviour in Rasmussen's model is similar to the situation in which strong expectations trigger specific schemata. In this case, a specific context i.e. the presentation of specific information activates a schema. Schemata are characterised by a very strong top-down control. In case of activated schemata, a specific sequence of perceptual, cognitive and behavioural actions is carried out. For example a road user that approaches an intersection that he passes every day will have specific activated schemata. Based on familiarity with the intersection a specific set of actions (schema) is triggered: first the driver looks to his right and then to his left in order to check for any approaching vehicles before turning right.

The problem with this type of behaviour is that a schema may activate such a strong top-down component that there is hardly any room for bottom-up selection of information. In case that new (bottom-up) information needs to be selected that does not fit the schemata 'the failure to apprehend' may occur. Consider the example of the driver approaching the intersection: if the driver does not expect cars approaching from the left side, then cars approaching from the left side may not be part of the schema. Even if traffic is approaching, the driver may not respond. This is exactly what has been found in accident data. Van Elslande and Faucher-Alberton (1997) refer to accident data that show that road users who are familiar with a site tend to perform their normal sequence of actions despite new or contradictory information. This clearly points to the strong top-down control, with little room for bottom-up features. The look-but-fail-to-see accidents, described in Chapter 1, are also related to activated schemata. In many cases, the driver looked in the appropriate direction (according to the activated schema) but failed to give priority to the other vehicle, most likely since they did not expect any vehicle to be

present. Apparently, the presence of another road user did not have strong enough bottom-up features to actually result in a response. Also Rumar (1990) explains these types of accidents by the road user having a partly incorrect expectation. This is confirmed by Brown (2005) who claims these accidents are particularly likely when driving on very familiar roads, with drivers using stereotyped search patterns. Herslund and Jørgensen (2003) confirm that experienced drivers may develop fixed routines for searching information. For example, drivers only scan the expected location of traffic signs, showing the strong top-down control (Theeuwes, 1991c, 1992c). If information is presented at a location that does not fit the activated schema, it will not be selected. But even if the information is selected e.g. because it is presented at a location that is part of the schema, it may still be insufficiently processed to break through this strong top-down control.

Chapter 4 also described vigilance as one of the four situations in which 'the failure to apprehend' can occur. This holds for classic vigilance tasks. However we do not consider the driving task to be a classic vigilance task, even though literature has described vigilance as 'a human factors concern in driving' (Mackie, 1977; Harris, 1977). The term 'vigilance' in the context of driving is only used to indicate a situation in which a driver is passively monitoring the outside scene rather than actively scanning the environment. In this sense, this type of behaviour can be characterised as being rule-based and strongly depending on schemata. Note however, that vigilance tasks are different than more common rule-based tasks because targets are very infrequent.

5.3 Knowledge-based behaviour and new tasks

Knowledge-based behaviour is found in new situations. For experienced drivers this can be driving in a new city or interpreting new traffic signs. An illustrative example is a Dutch driver who has to switch to driving on the left side of the road in the UK. The Dutch driver cannot rely on automatic task performance, nor on schemata or top-down control. Only by allocating all attentional resources to this new driving situation, the driver is able to perform this task.

However there is a severe risk in trying to change an automatic task to a knowledge-based task. In case of sudden and imminent situations that require an immediate response, things go wrong. Consider the Dutch road user, who has been driving on an empty rural road in the UK for an hour. If a car suddenly approaches from the front, automatic task performance takes over again; the mere presence of the car on collision course immediately makes the driver turn the steering wheel to the right hand side in order to avoid the vehicle. In the UK, the driver should have done the opposite, which may result in a frontal collision.

In case of knowledge-based behaviour, all information is basically new and not much top-down knowledge is available for selecting and processing this information. One could argue that most processing is done in a bottom-up manner. Performing a new task (or at a knowledge-based level) requires a high level of attention and is therefore very demanding. A driver receives a lot of visual input since all information needs to be processed basically in a bottom-up manner. Because top-down knowledge cannot guide the selection and processing of information, it is expected that knowledge-based behaviour is relatively slow. Because processing is relatively slow, not all information can be processed. There is too much competing information in the visual field, causing 'the failure to apprehend' simply because relevant information may not get selected. For instance, when driving in a new city, a driver has to find his way, look at directional signs, choose the right lane in time, pay attention to other cars, watch for zebra crossings, interpret the priority situation etc. Al these tasks together increase workload and result in a large competition between different task elements. Since the driver has no prior expectations of where important information is located (top-down control), he has to actively scan all information elements. Therefore the driver may be able to only select a limited amount of information, leading to a failure to select an important sign telling him or her that it is not allowed to enter that road. This may result in a frontal collision with a car coming from the other direction.

Knowledge-based task performance is most severely impaired by adding another (sub)task, since the extra task may divert attentional resources from the primary task of driving. An example is making a telephone call while driving (e.g. Strayer, Drews & Crouch, 2003; Strayer, Crouch & Drews, 2004; Burns, Parkes, Burton, Smith & Burch, 2002; Consiglio, Driscoll, Witte & Berg, 2003; Patten, Kircher, Östlund & Nilsson, 2004). In the Netherlands there is considerable debate about the need to further regulate hands free calling and driving at the same time. Some companies have decided not to wait for legislative measures and forbid their employees to make even hands free calls whilst driving (Intermediair, 2006).

In order to comprehensively illustrate the effect of 'the failure to apprehend' we elaborated Rasmussen's original model. The model is shown in Figure 5.1.

According to the elaborated model, the difference between the three levels of performance is explained by the level of bottom-up and top-down control, the level of practice, the level of attention and time that a task requires, the level of arousal, and the level of task load.

At each level, the risk for 'the failure to apprehend' results from a different cause.
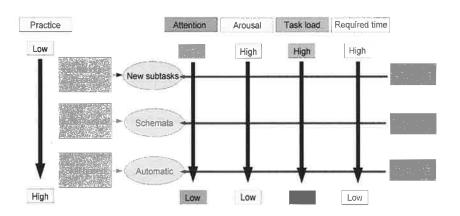
Figure 5.1 The elaborated task performance model, based on the model of Rasmussen (1986).
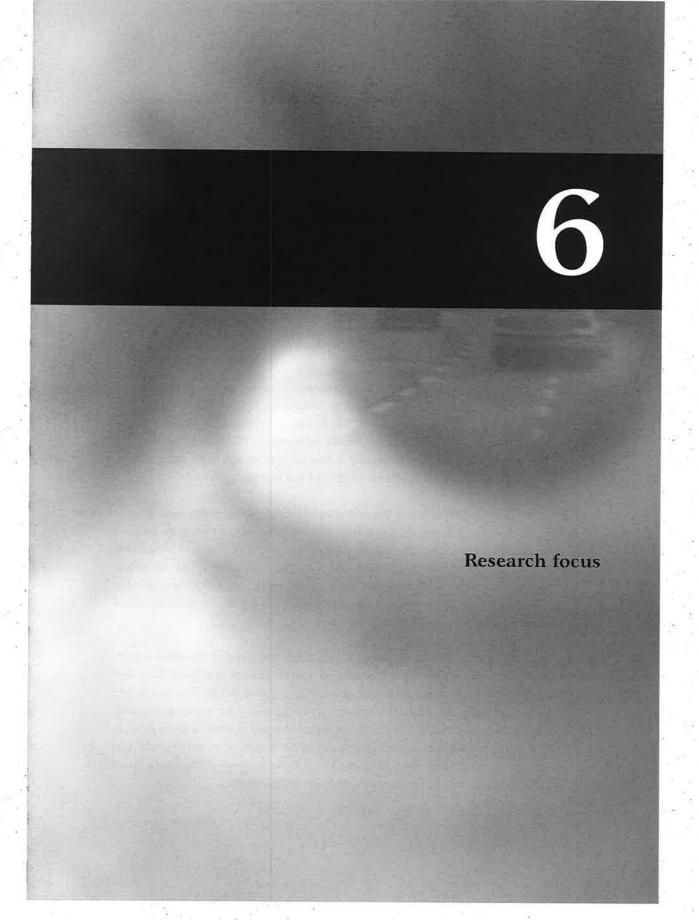
In case of knowledge-based performance, there is a high task load, but if the task load does not exceed the available attentional resources, performance may still be fairly good. Because the task is new and is hardly practised, performing the task takes quite some time, arousal is relatively high and selection and processing basically occurs in a bottom-up manner. In this case 'the failure to apprehend' is a result of failure to select the right information at the right time because of a limited processing capacity.

In case of rule-based performance, drivers have a strong top-down control and depend on the activated schema to select and process information. The task is fairly well practised, the level of arousal is not so high, nor is attention, task load and the time required for performing the task. 'The failure to apprehend' is the result of the strong top-down control, which is so strong that it does not allow the bottom-up input of signals that do not fit the top-down schemata.

Finally, in case of skill-based behaviour or automatic task performance, there is a direct link between a stimulus and a response. Information processing and responding is carried out entirely bottom-up, without any room for top-down control. The task is highly practised and the required level of attention is low; these tasks are not very demanding, arousal is normally very low and the time needed for performing the task is minimal. Therefore, in skill based behaviour 'the failure to apprehend' is explained by the lack of top-down control.

6

Research focus

The main focus of this thesis is to study 'the failure to apprehend'. The research presented in this thesis is used to verify the model presented in Chapter 5. In order to focus the scope of research, the driving task is used as a framework. In order to design countermeasures that may reduce the number of accidents related to 'the failure to apprehend' during driving, one has to understand the underlying mechanisms and identify the situations under which this phenomenon occurs. In the end, the ultimate goal is to use knowledge about expectations and visual information processing to design roads that force road users to respond to all relevant information.

6.1 Difference with CB and IB tasks

Even though the Change Blindness and Inattentional Blindness studies are important lab illustrations of the phenomenon that we are investigating here, it is important to note that there are also large differences between the conditions occurring in these tasks and driving behaviour.

First of all, quite a number of studies have used specific search tasks, with participants being instructed to search for or to focus on some items present in the visual field. However, in more natural tasks, like normal driving, people more or less monitor the scene and are not actively looking for specific information. This means that scanning the environment is done very differently in case of visual search tasks, since instructions are known to affect what items are fixated and therefore selected.

Secondly, there is a difference in the relevance of information between some Change Blindness and Inattentional Blindness tasks and the tasks used in this thesis. In quite some experimental studies, 'the failure to apprehend' is found in case of stimuli that are not that relevant for the task. In Chapter 3 we discussed already that 'the failure to apprehend' may result from an observer not seeing the need to respond if (s)he does not consider it to be relevant for the task. In this thesis, we focus on visual information that is highly relevant for the task.

A third difference between the focus of this thesis and Change Blindness experiments is the need to respond to a change. A specific feature of Change Blindness experiments is that it is the change that needs to be detected, not the information per se. In our daily lives, for example in driving, we are normally not specifically looking for changes in our visual environment but rather respond to what is there. Even in case of dynamic information, such as a traffic light changing from red to green, it is not the change that people have to respond to, it is the presence of the colour green in itself. This is a clear difference with the focus of this thesis.

In this line of reasoning, it is to be expected that 'the failure to apprehend' takes place if one is instructed to attend to something else (as is the case in some Inattentional Blindness experiments). Under those conditions the information is simply not selected. Also, if information is not part of the task that one performs, it is expected that one does not attend and therefore not select that information. It is to be expected that even when information is selected, it is not processed to a deep extent if it does not have any relevance for the task or any informational value in itself. In the current thesis it is therefore important to study tasks in which there is 'the failure to apprehend', most likely induced by expectations, even though the information is relevant for the task at hand. In case of driving, the information we study has to be important from a traffic safety point of view, with 'the failure to apprehend' resulting in safety problems. Also, we want to use a task in which road users are not specifically instructed to search for information. Since selecting and processing driving related items like traffic signs is part of the driving task, traffic signs do have informational value to a driver, and a failure to perceive traffic signs does have negative consequences for the driver, studying traffic signs and responses to traffic signs is a good starting point for studying the phenomenon. Also, detecting a change in a traffic sign or in a traffic situation will not be the main focus of this thesis, but responding to a new traffic sign or traffic situation will. In this case responding to the information that is there is important, and not the mere detection that the information has changed.

6.2 Research questions

The idea that 'the failure to apprehend' results from strong (but possibly wrong) expectations, due to a low attention level or due to low task load contrasts with the phenomenon resulting from a (too) high task load. In case of high task load, attentional or visual limitations explain why there is a 'failure to apprehend'; the task is so demanding or the amount of information presented is so high that a person cannot simply process all information available at a sufficient level to generate a response to everything presented. However, in case of strong expectations, low or passive attention and a low task load, limitations in what one can attend or process cannot be the explanation; despite the low effort of the task at hand and despite the fact that there are sufficient attentional resources available, there is 'the failure to apprehend'. The research questions of this dissertation will focus on expectations, inattention and low task load. Conditions of high task load are not discussed in the context of this thesis.

In general, the main research questions are:

1. What is the effect of developing expectations on eye movement behaviour in artificial and driving scenarios (i.e., glance duration to relevant and irrelevant information)?

2. What is the effect of developing expectations on responding to unexpected but relevant information?

3. Are observers able to inhibit a response if expected relevant information turns out to be information that does not require a response?

4. Is there a difference in glance duration between people who respond and those who do not respond to relevant information?

5. Do drivers respond to changes to the traffic situation after they have become familiar with the road environment?

6. Is there a difference in the effect of developing expectations on glance duration of relevant information between real driving and simulated driving?

7. What type of unexpected information does one respond to?

8. How similar does a road environment have be from one encounter to the next in order for road users to develop these expectations?

9. What type of information can help break through these incorrect expectations, resulting in the driver respond to unexpected information?

In order to keep control over what people expect and what they do not expect, all the (driving) tasks used in this thesis allow people to develop the expectations within the experimental task. All tasks used are dynamic tasks.

6.3 The experimental studies

The experimental studies of this thesis are a combination of more artificial tasks and driving tasks. Chapter 7 and 8 describe lab tasks that were developed in order to investigate the effect of developing expectations on glancing at relevant and irrelevant information. In these tasks, glance duration and responses to relevant and irrelevant information are measured that is either expected or unexpected. These abstract environments were chosen to study the concept of expectations and responding to

relevant information in a more controlled environment. Since the task of driving is highly trained, people already have a lot of expectations before the experiment starts. Therefore it was important to start from a baseline in which participants did not have prior expectations about the task.

Chapter 9 through 12 focus on the driving task and the traffic environment. The driving task is chosen as a real life task in which expectations, inattention and low task load are represented. In the driving task, responding to driving-related information is of crucial importance. In order to keep some control over expectations, all experiments allow the participant to develop task specific expectations during the experiment.

Chapter 7

Chapter 7 investigates expectations, glances and responses in a laboratory setting. In this study a rather abstract environment was created with a slight overlap with the driving environment. The environment is dynamic, with a flow of visual information approaching the observer (as is also the case in driving). The task of the observers is to decide for each item approaching them whether it is part of the task set (target) or not. By using a new and abstract task environment, observers do not have any expectations yet. This allows expectations to develop under controlled conditions. A large difference with the driving task is that in this task, observers are instructed to respond to specific predefined targets. When driving, the driver normally does not have a specific search task if he is driving in a familiar road environment.

The questions that we address in Chapter 7 are related to the effect of expectations on glancing at relevant and irrelevant information and the effect on responding to unexpected information. The question here is whether glance duration is different in a predictable environment compared to an unpredictable environment. In this study, predictable is defined as 'the order of targets and distractors is predictable'. Even though observers are not instructed that the order is predictable, they are able to develop expectations of when to expect targets and when to expect distractors. The other question that is addressed is: Are targets in the predictable task environment detected if they are not presented according to the predictable scheme and are there costs involved in the predictable condition?

Chapter 8

In Chapter 8, the same type of task environment is used, but with a slightly different task. Again, observers are asked to identify targets and ignore distractors. The effect of expectations is again the topic of this study. Together with the targets and distractors, additional (implicit) information is presented as a cue for an item being a target or a distractor. Observers are not informed about the additional information.

Here, responses to unexpected targets are compared to responses to unexpected distractors. Besides the questions already posed in Chapter 7, extra questions here are: How do people respond to irrelevant information if they expect it to be relevant? Are people able to use this extra information for identifying the targets and distractors? Is there a difference in glance duration between those who respond correctly and those who do not?

Chapter 9

Chapter 9 describes the first study of this thesis that focuses on the driving task. This driving task is performed in a low-cost driving simulator. By confronting drivers with the same road environment numerous times over numerous days, the expectations that people build up in that task environment are controlled. There are no specific instructions to the participants about what to attend and they are no instructions about the possibility of changing information. Participants are requested to drive as they normally do in their daily drive from home to work.

The route that people are driving in this study contains various intersections, houses, built-up and rural areas and various traffic signs. In this case, glance duration for traffic signs is measured as drivers get more and more familiar with the road. Also, driving speed is measured on the various road sections. In the last drive that participants make, a change is made to the traffic scene (change in priority, highly relevant). It is assessed how drivers, familiar with the environment, respond to this change in the traffic situation (different road markings and traffic sign) compared to people who do not have expectations with this specific task environment yet (glance duration, speed).

Chapter 10

Chapter 10 continues with the driving task. This study assesses the effect of getting familiar with the driving task on glance duration for traffic related items. Chapter 7, 8 and 9 all use simulated computer task environment, since this allows proper control over the task environment. The question addressed in Chapter 10 is what happens to glance duration when road users get familiar with a specific road environment.

In this study, participants drive a pre-selected route five times per day during a times period of one week. This allows them to get familiar with the road environment while still having some variation from drive to drive in type of traffic and weather conditions. The same route is also recorded on video, also with some variations in traffic and weather. This allows us to study whether glance duration in real driving is comparable to a situation in which participants watch video of the same road environment.

Chapter 11

Chapter 11 further assesses the expectations that people develop during driving. In this study, we employ a high-end driving simulator. People make various drives on the same road, but variation is made to the environment. The road has the same lay-out, traffic rules, curvature and intersections from drive to drive, but it in some conditions it has a different appearance (more or less trees, buildings, road width etc). After several drives, the traffic situation is changed and responses to this unexpected change are recorded. Responses of drivers in a varied road environment are compared with those in a road environment that always remains the same. Participants also receive different types of information to warn them for the changed situation. This study is also used to test what type of information is most effective in warning the driver.

Chapter 12

Again the focus is car driving and this time videos are used as stimulus material. The idea here is to study glance duration at traffic signs and to assess what sort of changes to traffic signs are perceived and which ones are not. Videos are made of a drive around the block, showing the video from the perspective of the driver. The videos are made in real traffic, so there are other cars, cyclists, pedestrians. Participants watch the video 5 times before a change is introduced. Participants are instructed to look and verbally respond to a driving related change.

In different conditions, people are confronted with a change of a particular traffic sign. The changes are varied in type of feature change (small changes, large changes) and how well they fit in the scene. Since the participants' task is to watch a video, we are not able to measure a driving response such as reducing speed. Glance duration at the various signs is recorded during the 6 'drives' and all participants are asked if they see any changes. This is asked after the video is stopped, immediately after the change. Glance duration between those who notice and those who do not can be compared. Independently of whether they report the change, they perform a recognition test. Different traffic signs (also the changed sign) are briefly shown and participants have to guess what sign is shown. The idea here is to test if there is better sign recognition for those people who encounter the changed sign. After the test, participants are told what the change has been to determine whether they can recall it after all. In one of the conditions, participants receive an auditory warning just before the change is introduced. This is done to study the effect of attention level on change detection.

Chapter 13

Chapter 13 discusses the results and makes a link between the literature and the various experiments performed for this thesis. While discussing the experimental results, we draw conclusions and focus on practical applications.

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7

Glance duration and manual response as a function of expectancies[1]

7.1 Introduction

Under some conditions, only a small part of the available attentional resources is directed to the task at hand. In these situations, people perform their task fairly well, while maintaining resources available for other tasks or thoughts. This phenomenon is typically present in well-practised tasks or vigilance tasks. Jerison (1970) and Warm (1977) state that vigilance tasks require sustained attention, with the tasks being prolonged and continuous. In a typical vigilance task, the targets occur infrequently in terms of time and are usually clearly perceivable when the observer is alerted to them. Compared to the number of distractors, targets occur a-periodically and without forewarnings. The observer's response typically has no effect upon the probability of appearance of the targets in vigilance tasks. A typical vigilance task would be inspecting individual items for classification (manufactured goods), or monitoring an ongoing process like in a radar air traffic control centre and vehicular control (Wiener, 1984). These tasks, while requiring sustained attention, may induce a low level of arousal (Parasuraman, 1984). Especially in an environment that is highly predictable (with a person having strong expectations about what will happen), not too much conscious attention may be paid to the task at hand. Mermall (1970) concluded that driving can be a task with minimal commitment, referring to the situation in which drivers are occupied with themselves (e.g. when day-dreaming), thereby reducing the interaction with the outer world. He states that drivers 'somehow' learn to drive without thinking about it or without being consciously aware of the driving situation. In these situations, people passively use their mental model to select important information from the environment, rather than actively scan the visual stimuli in the surroundings and update the mental model.

This kind of passive information processing will be the background of this chapter, referring to a state in which expectations have replaced a large part of the active information intake compared to a highly attentive person. This way of information processing requires little attention, leaving attentional resources to be distributed to other areas, for instance other tasks or thoughts. It is a very economic state of information processing, but the state is only adequate if the person's expectations are correct. In case something unexpected happens (that does not correspond with the expectations), one could either miss crucial information completely (fail to select, or select but fail to respond) or there may be a delay in manual response time as a result of the extra time needed to interpret this information. If this would happen in a professional situation, the costs of the economic state of information processing may be failing to notice an unexpected detail or responding too late, possibly resulting in accidents.

Some evidence for the effect of expectations on searching for targets has been provided in static experiments. Meyers and Rhoades (1978) looked at the effect of expectancy on visual scan patterns and showed that searching for an object at a non-predictable location was much slower than searching for an object at a likely location. This implies that participants direct their visual scan pattern according to where participants expect information to be, resulting in an effective search if these expectations are correct. Literature suggests that the pattern of eye movements somehow indicates the goals of the observer and possibly the area of interest (Liu, 1999; Stark & Ellis, 1981). Theeuwes (1991c) investigated the effect of expectation on top-down (active) visual search of every-day traffic scenes presented on slides. The study showed that expectancies about the location of the target (traffic signs are normally located on the right side of the road) had an effect on the eye scan behaviour (searching on the right side of the road). Search behaviour seemed to be based on the meaning and content of a scene in combination with the object one searches for. In contrast to Meyers and Rhoades, Theeuwes did not find that participants adjusted their search strategy when they learned that expected location was not always a good cue for responding. Search strategies remained the same even in conditions in which the target object was consistently presented at unlikely positions. Participants always tended to search at the most likely locations, leading to a No-answer if the target was not found in this place.

Most studies, dealing with visual search, are concentrating on static environments, such as pictures or presentations of scenes on a computer monitor. However, in tasks with a presentation at one discrete moment in time, visual search is assumed to be more active than it may be in dynamic scenes, in which there is a continuous stream of stimulus material and not a sequence of pictures. Few experiments have studied the type of visual information that gets perceived in a dynamic environment when people have strong expectations, directing little attention to actively scanning the environment. How do these expectations influence glances in the visual environment? Do people respond more adequately to expected information since this is in accordance with what people expect or does inconsistent information lead to a more adequate response since this is information with a high informational value and therefore attracts more attention? The questions that will be asked are related to these issues:

1. Will glances be different if participants are able to develop expectations of when to expect targets compared to the glances of participants without these expectations?
2. Will targets that are presented in a way that is in contradiction with the expectations (irregularities) be missed and if not, will manual response times to these targets be higher?

7.2 Experiment 1

7.2.1 Method

The assumption behind the idea of economic information processing is that if people do not have strong expectations about the environment, they are less certain of where important information may be located and they spend more time glancing at all stimuli. If people develop expectations because of sequential exposure to a certain scene, they feel more certain, not feeling the urge to glance at all stimuli. In Experiment 1, the hypothesis was tested that people with expectations about what information is relevant and what information is not, will spend more time looking at information that is assumed to be relevant. A second hypothesis is that if information is presented that does not correspond with the expectations, the information will be missed.

In order to test these assumptions, a lab task was developed that had some correspondence with a simulated driving environment. The task environment consisted of a road, grass along the sides of the road and relevant objects (the stimuli) and irrelevant objects (corresponding to houses or trees in the surroundings). Scenes from the task are shown in Figure 7.1a and 7.1b.

In order to test the hypotheses, manual responses and glances were recorded. Eye movement studies have yielded some valuable results in exploring visual scan patterns, especially in dynamic environments. If participants move their eyes toward a new position, attention will be moved along to that same position (Hoffman & Subramaniam, 1995). Eye movement measures can be a valuable tool for exploring the effect of expectation on visual information perception, or at least reveal something about how expectations affect visual scan patterns.

Participants
Thirty participants took part in the experiment. Their ages varied from 22 to 63 and both male and female Dutch participants were included. All participants reported to have good visual acuity. Half of the participants were part of the predictable condition and half of the group was part of the random condition. Participants were randomly assigned to one of the two experimental conditions. Participants were paid for their participation.
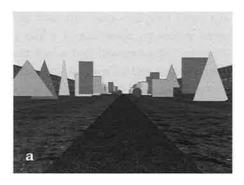
Apparatus
A corneal-pupil reflection measurement device (Inducom Inc.) was built into an experimental configuration, suited for measuring eye movements and recording the manual responses. This video-based system sampled at 50 Hz, with the infra-red light source and the eye camera being situated slightly at the right of the eye level (approximately 0.75m from the participant's eye). A high-speed processor (Scanbeam

Inc.) computed the centre of both cornea and pupil reflection and calculated the difference vector. The output of the high-speed processor, consisting of x and y co-ordinates, was entered into a computer (Pentium 166 processor) that mixed the data on-line with the task environment that was presented and the manual responses that participants made. The images were generated by an Accel Galaxy video display adapter and displayed on a 19″ SVGA colour monitor. The display resolution was 1280x1024 with a high colour (16 bits) palette at 75 Hz. A mouse button was used for the manual responses.

Task

As is shown in Figure 7.1, the task environment consisted of a virtual grass field with a virtual road, on which the participants virtually moved forward. Along the side of the road (on the grass field), all kinds of object shapes were placed that were not relevant to the task participants had to perform (cf. houses along a road). Along the road, purple circles appeared on the horizon and they became larger as the participant was moving through the environment alongside the road with a continuous pre-set speed. If an object was close to the participant, it would be on the right side of the road and finally disappear from the screen. Every 1.1 seconds, a purple stimulus passed by. The task of the participants was to decide whether the closest (and thus largest) object was a circle (distractor) or an oval (target). Objects were always circles, but if they were the closest object to the participant, they could either stay a circle or they could change into an oval. If this change occurred, participants had to press a mouse button to indicate they noticed the target. In cases in which the circle did not change (distractor), they did not have to take any action. This type of stimulus (that could either change into a target or stay a distractor) was used in the experiment to force participants to always look at the largest stimulus. This was necessary in order to have accurate eye movement recordings and to make sure that the stimuli they responded to could be identified. No feedback was given about their performance.

Two experimental conditions were used. Participants were either part of the 'predictable condition' or of the 'random condition'. In the predictable condition, the order in which the targets (ovals) were presented among the distractors (circles) was predictable, with the targets and distractors alternating. The number of targets was equal to the number of distractors. In the random condition, the sequence of targets and distractors was random, so participants could not predict whether the next stimulus was going to be a target or a distractor. Also here, the total number of targets was equal to the number of distractors (and equal to the predictable condition). Figure 7.1 shows a static picture of the dynamic scene that the participants would encounter in Experiment 1.
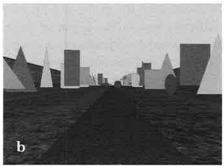
Figure 7.1 The task environment of experiment 1, with (a) showing a distractor (circle) and (b) showing a stimulus that has just turned into a target (oval)

Participants did not have to pay any specific attention to the yellow or orange objects, nor to the road or the grass. If participants detected a target, they had to press a mouse button. The task was not to respond as quickly as possible but as accurately as possible (therefore, manual response times were not measured). All participants received three sessions of 10 minutes, with a 5-minute break in between. In Session 1, the random condition was completely random and the predictable condition was completely predictable. In Session 2, the random condition was still completely random, but in the predictable condition, one irregularity was introduced. This irregularity consisted of a target where a distractor would normally have been shown. This happened after about 8 minutes. In Session 3, two irregularities were included in the predictable condition, one extra target instead of a distractor after about 3.3 minutes and one after about 9.3 minutes. The random condition would also have the extra ovals, but they cannot really be called irregularities since there was no predictable pattern in the presentation order.

Procedure
After reading the instructions, participants were seated in front of the monitor of the computer. Their head was resting in a chin rest, which was located 0.97m from the screen. Before starting the experiment itself, the eye movement equipment had to be calibrated to the eyes of the participant. After the calibration, a dynamic preview of a session was given for about one minute, to give the participants an idea of the environment and the stimuli they were about to see and what they had to respond to. Participants could start the experiment by pressing a mouse button. Participants were instructed to press the mouse button to indicate the presence of a target. The experiment lasted about 45 minutes per participant, with three sessions of ten minutes per participant.

Statistical analysis

For eye movement data, the percentage of total glance duration was calculated. The time that a participant looked at the largest and closest stimulus was divided by the total time that this stimulus actually was the largest and closest stimulus. The percentage of total glance duration was defined as 100% if a participant started looking at a stimulus as soon as it was the largest and closest stimulus (this would be after the preceding stimulus disappeared from the screen) and glanced at the stimulus until it entirely disappeared from the screen. A glance at a stimulus was made if participants looked in the horizontal area of 4/3 times H (height of the stimulus) to the left of the stimulus or 3/3 times H to the right side of the area (to be consistent, height was the criterion, since this remained the same in targets (ovals) and distractors (circles). The definition of the area on the right side was smaller, since participants tended to look on the left side of objects. This was probably due to the fact that objects were moving from left to right side, so following a target led to glances at the left side of the stimulus. This means that the area used for the analysis of glances was focussing on stimuli just before the target disappeared from the screen. The height of targets and distractors, just before they disappeared from the screen, was always the same.

Since the data set for the percentage of glance duration was extremely large, five sequential data points for the largest stimuli (classified by targets and distractors) within one participant were averaged into one new data point. This was done after it was checked whether there was a difference in variance between the 5 sequential points. This did not turn out to be the case. When an irregular target was introduced in Sessions 2 and 3, the data points around the irregularity were not averaged, so only raw data were analysed just before and after the irregularity. The data were analysed with ANOVAs (analysis of variance).

Data of seven participants had to be removed from the analysis since there were too many missing glance data due to technical failures of the eye movement equipment. This meant that the eye tracker had not been able to measure the glances during the entire experiment and therefore too many data samples were missing. Of those seven participants, three participants were part of the predictable condition and four were part of the random condition. Therefore, the total number of participants in the random and the predictable condition was 11 and 12, respectively. The ages of the final group of participants did not differ from the original sample.

7.2.2 Results

Session 1

In Session 1, no irregularities were present in the predictable condition. In the random condition, participants pressed the mouse button when a distractor was present (false alarm) in 1.81% of the cases. Plus they failed to respond to a target

(miss) in 5.01% of the cases. For the predictable condition, the error rates were 0.90% and 3.89%, respectively. There was a marginally significant difference in d^1 between the two conditions [$t(14) = 0.10$, $p < 0.092$], with no significant difference in sensitivity between the two conditions.

There was a main effect of Stimulus (target or distractor), showing a higher percentage of glance duration for targets compared to distractors [$F(1,21) = 32.12$, $p < 0.0001$]. Also a main effect was present of Condition (random/predictable), showing longer glances for the random condition [$F(1,21) = 10.70$, $p < 0.0036$]. There was a 2-way interaction between Stimulus and Condition, that showed that the longer glances at targets compared to distractors were only present for the predictable condition [$F(1,21) = 16.65$, $p < 0.0005$]. This interaction is shown in Figure 7.2.
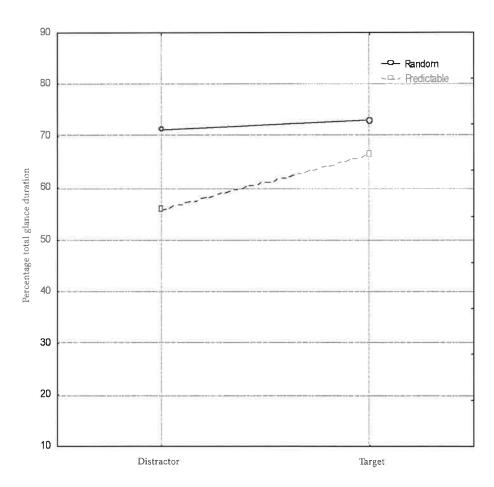

Figure 7.2 The interaction effect between Condition and Stimulus on percentage glance duration in Session 1 of experiment 1, with shorter glances at the distractors in the predictable condition.

In the random condition, in which participants were not able to develop any expectations on when a target would occur, no difference was found between the distractors and the targets. However, Figure 7.2 also shows that although participants in the predictable condition reduce their glance duration for the distractors, they do not use their expectations to increase the glance duration for targets.

Session 2

The difference between Session 1 and Session 2 was that after the session had run about 8 minutes (445 out of the 575 stimuli), an extra target (oval) was shown, which means that for the predictable condition, one circle was replaced by an oval. This extra target is called the irregularity.

In the random condition, participants pressed a mouse button when it was a distractor (false alarm) in 1.12% of the cases. In 3.35% of the cases, participants in the random condition did not respond to a target (miss). For the predictable condition, this was 0.85% and 1.76%. Here, there was no significant difference in d^1 between the two conditions $[t(16) = 0.57, p < 0.57]$, indicating no significant difference in sensitivity.

In the predictable condition, 8 out of the 12 participants did not respond to the appearance of the extra target, probably indicating that they did not notice this. In the random conditions, all 11 participants responded correctly to the appearance of this target. As for the percentage of total glance duration, data were again averaged over 5 sequential trials. The percentage of total glance duration (summation of target and distractor glance duration) did not differ between the random and the predictable condition (which was to be expected, since we only expected a shift in percentage glance duration between targets and distractors). A higher percentage of total glance duration was found for the targets $[F(1,21) = 32.16, p < 0.0001]$. Similar to Session 1, the longer glances at targets were only present in the predictable condition $[F(1,21) = 7.21, p < 0.014]$. Figure 7.3 shows the percentage of glance duration just before and after the irregularity for the random and the predictable condition.

If we only look at the data points around the irregularity (10 data points before and 10 data points after the irregularity (including the irregularity itself)) without averaging these data, a lower percentage of glance duration after the irregularity is found only for the predictable condition, which may indicate a change in glance pattern $[F(1,21) = 11.10, p < 0.003]$. This effect was also present if those participants who did not respond to the irregularity were removed from the analysis. Moreover, this effect lasted for 15 stimuli after the irregularity.
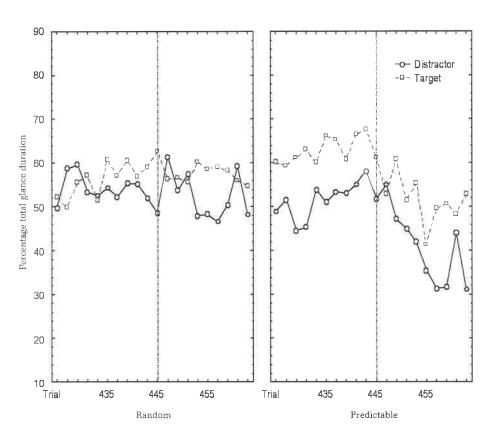
Figure 7.3 The percentage of total glance duration for the two experimental conditions in Session 2 of experiment 1 with 10 stimuli before the irregularity and 10 stimuli after. Here data are not averaged, so every point on the x-axis is one glance at one stimulus.

Session 3

In Session 3, two irregularities were used, one after 185 out of the 575 stimuli (about 3.3 minutes) and one after 519 stimuli (about 9.3 minutes). Also here, this meant that what was expected to be a circle in the predictable condition changed into an oval.

In Session 3, participants in the random condition pressed a mouse button when it was a distractor (false alarm) in 1.14% of the cases. In 2.86% of the cases, participants in the random condition did not respond to a target (miss). For the predictable condition, this was 0.56% and 2.10%. Also here, the sensitivity between the different conditions was not significantly different [$t(13) = 0.37$, $p < 0.72$].

Of the 12 participants in the predictable condition, 5 participants responded to the first irregularity. All participants that responded to the irregularity in Session 2 also responded to the first irregularity of Session 3. For the second irregularity in
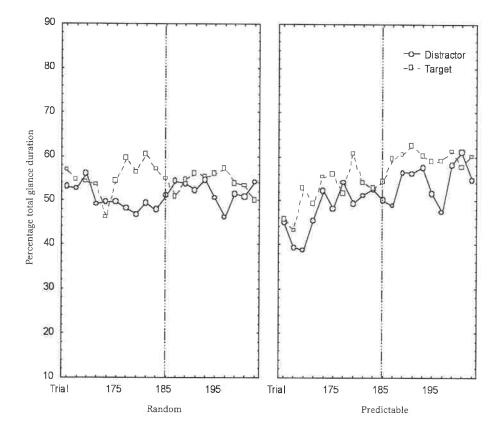
Figure 7.4 First irregularity in Session 3 of experiment 1, with one data point representing the percentage total glance duration for one stimulus.

Session 3, also 5 participants responded. Only one participant that responded to the first irregularity did not respond to the second one. In the random conditions, all 11 participants responded correctly to the appearance of this target.

If we look at the averaged data, again no main effect was found of Condition on the percentage of total glance duration (summation of target and distractor), which was to be expected. Also in this session, a higher proportion of glance duration for targets compared to the distractors was present [$F(1,21) = 7.79$, $p < 0.01$]. This time however, the percentage glance duration to targets and distractors did not differ between the random and the predictable condition. If we look at the data that were not averaged over 5 trials and assemble the stimuli around the first irregularity (10 before and 10 after the irregularity (including the irregularity itself)), there are no indications of a change in glance pattern after the irregularity, which is clear from Figure 7.4.

In line with the first irregularity, the analysis of the 10 data points around the second irregularity showed no effects; it seems that in Session 3, the difference in percentage of glance duration between targets and distractors that was present in Session 1 and 2 had disappeared.

7.2.3 Discussion
Hypothesis 1: Difference in glances with expectations
The experiment showed that there is a difference in the way people glance at stimuli if they have expectations about what stimulus will be a target and which one will be a distractor. There is no difference in glance duration for the targets and distractors if they are presented according to a random pattern, but there is indeed a difference if they are presented according to a predictable pattern. If the order of presentation is predictable, less time is spent glancing at the distractors. This difference between glance duration for targets and distractors for the predictable condition disappeared after some irregularities were introduced, possibly adjusting the expectations. However, because of the absence of a control condition, in which no irregularities were introduced, the presence of this phenomenon remains to be unknown.

Hypothesis 2: Missing targets in case of irregularities
Session 2 and 3 were used to see what happens if a target is not presented according to the expectations. In case of Session 2, 8 out of the 12 participants did not respond to the target at all. This meant that 2/3 of the participants probably did not notice the target (or at least failed to respond) since they expected to be confronted with a distractor and they spent less time glancing at the stimulus. This shows there are indeed some indications that there are misses in case that information does not fit the expectations. For the first irregularity in Session 3, only 5 participants responded to the extra target. This meant that again, almost 2/3 of the participants missed the target since they expected a distractor. In case of the second irregularity of Session 3, also 5 participants responded to the irregularity. Although these participants were not exactly the 5 responding to the first irregularity of the second session, 4 out of the 5 participants were. This only strengthens the assumption that it might be due more to the particular glance strategy of the participants than due to a change in glance strategy after noticing the first irregularity.

Since the difference in glance strategy between the random and the predictable condition disappeared in Session 3, this is an indication that participants indeed changed their strategy based on the irregularities. This might be evidence that participants gradually changed their glance strategy after encountering some irregularities such that their new strategy was similar to that used by participants in the random condition. However, a control condition with no irregularities presented would have to be introduced in order to explain this phenomenon.

7.3 Experiment 2

7.3.1 Method

Experiment 2 was similar to experiment 1. The key differences were the type of stimulus, addition of a control condition, measurement of manual response times (RTs) and a slightly different calculation in the percentage of total glance duration.

The character of the stimuli was changed in order to see if the same results would be found with different stimulus material (change in letter instead of shape). In order to allow a more general interpretation of the data, an extra condition was added in experiment 2. Rather than have the participants in the predictable condition have sessions both with and without irregularities, experiment 2 had three between-participants conditions, 1) Random, 2) Predictable with no irregularities and 3) Predictable with irregularities introduced.

The extra condition was a predictable condition in which no irregularities were present. This condition was lacking in experiment 1. Also, RTs to the appearance of the targets were measured in experiment 2. Measuring RT provides further data on a participant's information processing strategy. Failure to press the mouse button would suggest that the participant did not process the information, and hence, could not identify the appearance of a target. Measuring RTs also allowed more adequate calculation of percentage of total glance duration. The size of targets and distractors, just before they disappeared from the screen, was always the same. Since it makes sense that participants stop glancing at a target as soon as they identify it as a target and press the mouse button, the proportion of the total glance duration will have to take this into account. By estimating the percentage of total glance duration for targets as the proportion of the time until the mouse button was pressed, the data are more useful.

The hypotheses were similar to experiment 1, with an extra hypothesis that unexpected information would lead to a delay in RTs.

Participants

Twenty-seven participants took part in the experiment. The participants' age varied from 18 to 35 and they were all Dutch students (male and female). All participants reported to have normal or corrected to normal visual acuity. All participants were randomly assigned to one of three experimental conditions, with 9 participants in every condition. All participants were paid for their participation.

Apparatus

The apparatus used for presenting the task and recording responses was equal to experiment 1 (Accel Galaxy video display adapter and 19" SVGA monitor).

However, a different eye tracking system was used, made by Iscan Inc. (also using the corneal-pupil reflection technique). This system was more accurate than the one described in experiment 1. The processor sampled at 60 Hz, with the eye's pupil and corneal reflection positions being calculated with 12-bit resolution. The eye camera with the infra-red light source was positioned at the same location as in experiment 1. The video-based system sampled at 250 Hz. Again, the output consisted of x and y co-ordinates, and was entered in the same Pentium 166 processor. Also here, the definition of a glance at a stimulus was 4/3 times Height on the left side and 3/3 times Height on the right side. Participants were instructed to use the mouse button to indicate the presence of a target.

Procedure

After reading the instructions, participants were seated in front of the computer screen with their heads on a chin rest. Before the start of the experiment, the eye movement equipment had to be calibrated. After completing the calibration process, a preview of a session was given for about one minute, to give the participants an idea of the environment and the stimuli they were about to see and what they had to respond to. The mouse was used as a response button. Participants could start the experiment themselves by pressing a mouse button. Per participant, the experiment lasted 45 minutes, consisting of four sessions of seven minutes each. In between sessions, participants received a short break.

Task

For this experiment, the same lab task was used as in experiment 1. However, the character of the stimuli was changed and there were three experimental conditions instead of two. Participants were either part of the predictable condition,
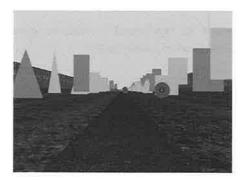

Figure 7.5 The task environment of experiment 2, showing a stimulus that has just turned into a target (O). The stimulus behind the target is still a Q.

the predictable+ condition or the random condition. In the predictable condition, the order in which the targets (in this experiment Os instead of ovals in experiment 1) are presented among the distractors (in this experiment Qs instead of circles in experiment 1) was predictable, with one O being followed by one Q, after which another O follows etc. The task environment is shown in Figure 7.5.

Treisman and Gelade (1980) and Treisman (1988) stated that if combinations of features are required for object recognition, visual spatial attention is required. They stated that attention is required when features must be located or combined in order to specify objects. Therefore, in this experiment, we have chosen to make a distractor almost similar to a target, with the only difference being the presence of one feature.

The number of Os was equal to the number of Qs. A stimulus always started at the horizon as a Q (circles in experiment 1), and if it approached, the largest stimulus (nearest to the participant) would either remain a Q (remain a circle in experiment 1) or it would change into an O (changed into an oval in experiment 1). Compared to experiment 1, there was no gradual change from distractor to a target (in which a circle turned gradually into an oval) but this would be a change at one moment in time, with the extra leg of the Q disappearing in case of a target. The physical place where a distractor could change into a target could vary a little in order to prevent participants knowing the exact location beforehand (a simulated distance between 50 and 25 meters from the participant).

In the predictable condition, every other Q would turn into an O. In the predictable+ condition, the sessions started out like the predictable condition. The only difference was that in the predictable+ condition, some irregularities were introduced. In Session 2, a Q changed into an O (extra target) after about 5.2 minutes (or 276 stimuli) of the total 7 minutes of the session. According to the predictable order, participants would expect a distractor. The same irregularity appeared in Session 3 after about 2.4 minutes (after 127 stimuli) out of 7 minutes. Here also, an O appeared where normally (according to the predictable pattern) a Q would have appeared. Two irregularities were present in Session 4, one after about 1.2 minutes (65 stimuli) and one after about 6.0 minutes (318 stimuli). Besides these irregularities, the session of the predictable+ condition followed the same predictable order as in the predictable condition. The sequence of the targets and distractors in the random condition was completely random, with an equal number of Qs and Os. The experimental configuration of experiment 1 was used, except for a different eye-movement measurement device.

Participants had to make a manual response every time a Q turned into an O. They were told that Qs could only turn into Os just before they disappeared off the screen. It was stressed that the manual response had to be as accurate and as fast as possible. Participants did not need to respond to the Qs that remained a Q (distractors). No feedback was given about their performance. Between the sessions, the participants had a five-minute break.

Statistical analysis
The same types of analysis were used as in experiment 1. Since in experiment 2, RTs had to be analysed as well, t-tests for dependent samples were used, comparing the individual mean with individual manual response times.

7.3.2 Results
The data of all participants were included in the data analysis since, in contrast with experiment 1, there were no technical failures of the eye movement equipment.

Percentage total glance duration Session 1
Per stimulus, the percentage of total glance duration was computed. If a participant would look at a stimulus when it was the largest one on the screen, followed it on the screen as it was getting closer, and stopped looking at the target when pressing the response button, the percentage of total glance duration was 100%. For the distractors, the time was 100% if participants started glancing at the distractor as soon as it was the largest on the screen and were still looking when it disappeared from the screen. As soon as the stimulus disappeared from the screen, the measurement for that stimulus was ended. Since the stimulus could quickly change into a target, the task required participants to keep glancing at distractors until they disappeared from the screen.

For the percentage of total glance duration, there was a higher percentage for targets compared to distractors [$F_{(1,24)}$ = 37.40, $p < 0.0001$]. Target glance durations were significantly longer than distraction glance durations, but only for the predictable and the predictable + condition, not for the random condition [$F_{(2,24)}$ = 7.79, $p < 0.0023$]. This interaction is shown in Figure 7.6.

Manual response times Session 1
Manual response times were calculated as the time between a Q turning into an O and clicking the mouse button. For Session 1, longer RTs were found for targets for the random condition (420 msec) compared to the predictable and the predictable + condition (360 msec) [$F_{(2,23)}$ = 3.65, $p < 0.04$].
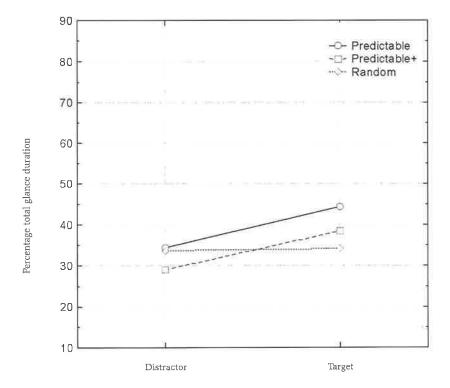
Figure 7.6 The interaction between Condition and Stimulus on glance duration for the three experimental conditions in Session 1 of experiment 2.

Percentage total glance duration Session 2

In Session 2, one irregularity was present in the predictable+ condition after 276 stimuli. Again, longer glances at the targets compared to distractors were only present for the predictable and the predictable+ condition, not for the random condition [$F_{(2,24)} = 4.90$, $p < 0.016$]. These results are similar to the results obtained in Session 1.

In order to see whether the glance strategy in the predictable+ condition changed after introducing the irregularity, the data of the 10 stimuli before the irregularity and the 10 stimuli after were analysed. The overall glance durations after the irregularity did not differ from the ones before the irregularity [$F_{(1,24)} = 1.07$, $p < 0.31$].

Manual response times Session 2

In the predictable + condition, 4 out of the 9 participants did not respond at all to the irregularity. For those participants that did respond, a t-test for dependent samples showed that there was only a significant difference between the mean RT in the session and the RT to the irregularity itself, indicating participants who did notice the irregularity responded slower than they normally did to targets (mean delay for all participants was 330 ms) [$t(4) = 4.15$, $p < 0.014$]. The other RTs (before and after the irregularity) did not significantly differ from the mean RT. Also, the RTs for the random or the predictable condition did not show any difference from the mean RT around the time of the irregularity. Figure 7.7 shows the RTs for the predictable + condition around the irregularity.
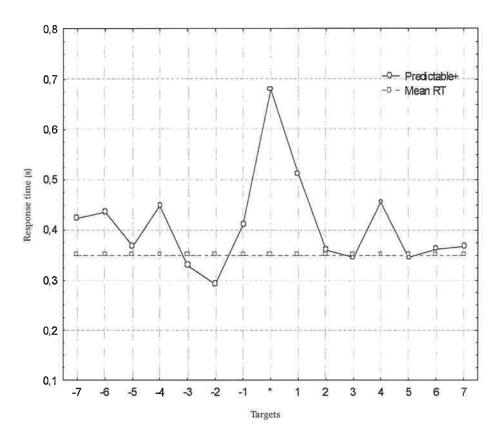

Figure 7.7 The RTs of the predictable + condition in Session 2 of experiment 2 around the time of the irregularity, indicated by *, in comparison to the mean RT in that condition.

Percentage total glance duration Session 3

In Session 3, 1 out of 9 participants in the predictable+ condition did not respond at all to the irregularity. For Session 3, again an irregularity was introduced for the predictable+ condition after 127 stimuli (the second irregularity in the complete experiment). Similar to Session 1 and 2, more time is spent on glancing at targets than at distractors for the predictable and the predictable+ condition only [$F(2,24)$ = 7.16, $p < 0.004$].

When analysing the glance durations close to the irregularity (10 trials before and 10 after the irregularity), no main effects or interactions were found, which was to be expected if participants would have changed their glance strategy after noticing the irregularity. This effect was not present, even if participants that did not notice the irregularity were excluded from the analysis.

Manual response times Session 3

For Session 3, the same analysis was done for the RTs around the irregularity. Altogether, 1 out of the 9 participants did not respond to the irregularity. RTs before and after the irregularity were analysed and all RTs (including the RT to the irregularity) were compared to the mean RT for the entire session. Also in this case, only the RT to the irregularity was significantly higher (with an increase of about 200 ms) than the mean RT in the predictable+ condition [$t(7)$ = 4.13, $p < 0.005$]. The other RTs were not significantly different from the mean RT. This increase in RT was not present for the predictable condition around the time of the irregularity, nor for the random condition.

Percentage total glance duration Session 4

In this session, two irregularities were introduced. The results of Session 4 were similar to the previous session: longer glances at the targets only in the predictable and the predictable+ condition [$F(2,24)$ = 6.09, $p < 0.007$]. When analysing the 10 trials before and after the first irregularity, no main or interaction effects were present. The same holds for the second irregularity.

Manual response times Session 4

Two out of 9 participants in the predictable+ condition did not respond at all to the extra targets. For the RTs around the time of the first irregularity in Session 4 for those participants who did respond, RTs to the irregularity were about 150 ms higher than the mean RT in that session [$t(6)$ = 2.81, $p < 0.03$]. RTs to the target shown after the irregularity were about 130 ms higher than the mean RT in that session [$t(6)$ = 0.56, $p < 0.02$].

Again, 2 participants did not respond at all to the second irregularity. Of those participants who did respond, the RTs to the irregularity (extra target) were about 310 ms higher compared to the mean RT [$t(6) = 4.35$, $p < 0.005$]. RTs to the first target after the second irregularity were about 230 ms higher [$t(6) = 2.85$, $p < 0.03$]. The RTs before the irregularity were all not significantly lower than the mean.

7.3.3 Discussion

Just like in experiment 1, the assumption was tested that participants with expectations about when to expect a target and when to expect a distractor will glance at stimuli differently than participants who do not have these expectations. A second assumption was that if something happens that is not in correspondence with these expectations, this information will either be missed or RTs will be increased.

Hypothesis 1: Different glance strategy based on expectations
In all sessions, a difference can be found in the way participants glance at the stimuli in the different conditions. In the condition in which participants were not able to develop any expectations on which stimulus will be a target and which one will be a distractor, no differences were found in the time that participants spent looking at the targets compared to the distractors. For the two conditions in which the targets and distractors were presented according to a predictable pattern (the predictable and the predicatable+ condition), participants spent less time glancing at the distractors compared to the time glancing at the targets. There was no clear change of glance strategy in the predictable+ condition after the irregularities.

Hypothesis 2: Missing information or higher RTs in case of irregularities
This assumption could only be tested by including some irregularities in the predictable+ condition. In the predictable condition, no irregularities were included and in the random condition, the irregularity was not really an irregularity since there was no predictable pattern to begin with.

The irregularity in Session 2 was missed by 4 out of the 9 participants, who did not respond to the target at all. The irregularity in Session 3 was missed by 1 out of the 9 participants. The 2 irregularities in Session 4 were missed by 2 participants. Altogether there was one participant who did not notice (or respond to) any of the irregularities. When we look at the manual response times of those participants who did respond to the irregularity, increased manual response times for irregular stimuli were found compared to expected targets. On average, an increase in manual response times of 330 ms was found for the first irregularity. This can also be called the 'cost' of expecting something that doesn't turn out to be true. For the second irregularity, this cost is about 200 ms and for the third 150 ms and for the last

irregularity 310 ms. These costs are very high when the nature of the average RT is considered. Sometimes (in case of the first irregularity) these RTs to irregularities are almost twice as high as the average response time in that particular session.

This indeed does confirm the hypothesis that less time is spent glancing at stimuli that are not considered to be important, with the costs being reflected in missed targets or long RTs if the expectations were not correct.

7.4 General discussion and practical implications

The combined results of experiments 1 and 2 showed that for both types of stimuli (changing shape in experiment 1 and changing letter in experiment 2), participants glance differently if they have expectations about what stimuli will be the targets and what will be the distractors. In the predictable condition, less time is spent glancing at distractors. Manual response times are also faster if the stimulus that one expects to be a target is a target indeed. For those participants that do not have expectations about the stimuli, the same amount of time is spent glancing at targets and distractors and RTs to targets in the random condition are higher compared to a predictable condition. However, if some information is included that is not in congruence with the expectations people have, this information is either missed or the RT to the appearance of the irregular targets is high, with manual responses even being slower than in the random condition.

The results support the hypotheses described in the introduction. More time was spent on what is considered to be important and less time was spent on what was considered to be irrelevant. Although this is a very efficient way of using knowledge (or what is considered to be knowledge) in order to divide our attention, it may be very inefficient if this knowledge does not turn out to be true. Important items can be missed, and even if they are noticed, correct manual responses are very slow. In the classical attention theories, these results fit into the framework of top-down processing. As Theeuwes (1991c) already stated, expectancies about the location of a target (traffic signs in his case) had an effect on the efficiency of the search behaviour. The current results also indicate that expectancies about the location of targets based on experience with the task direct glance durations, and may have negative consequences in case these expectancies are incorrect, showing the importance of top-down search. This phenomenon may have huge negative consequences in real life for tasks that are performed top-down, directed by expectancies developed while performing the task. Here we can think of operator monitoring tasks or scanning visual information during driving. If people who work at the customs of an airport have specific expectations of what they may find in suitcases, deviant information

may be missed easily. If drivers expect to encounter a certain traffic situation (since they have been for years) but it has changed, they may not register the changed information or respond too late. Before any conclusions like this can be drawn for practical situations, more research will have to be done to investigate this phenomenon in more real-life situations. Although this study is a good first step, the focus of the study is too limited to generalise all results. This study is limited to a single task paradigm and the head was always kept in a fixed position, something that is not very applicable to real-life tasks. Only after exploring this phenomenon in more realistic tasks, knowledge can be gathered about what can be done in order to break through these expectations and turn this economic visual information processing into a more active visual information intake.
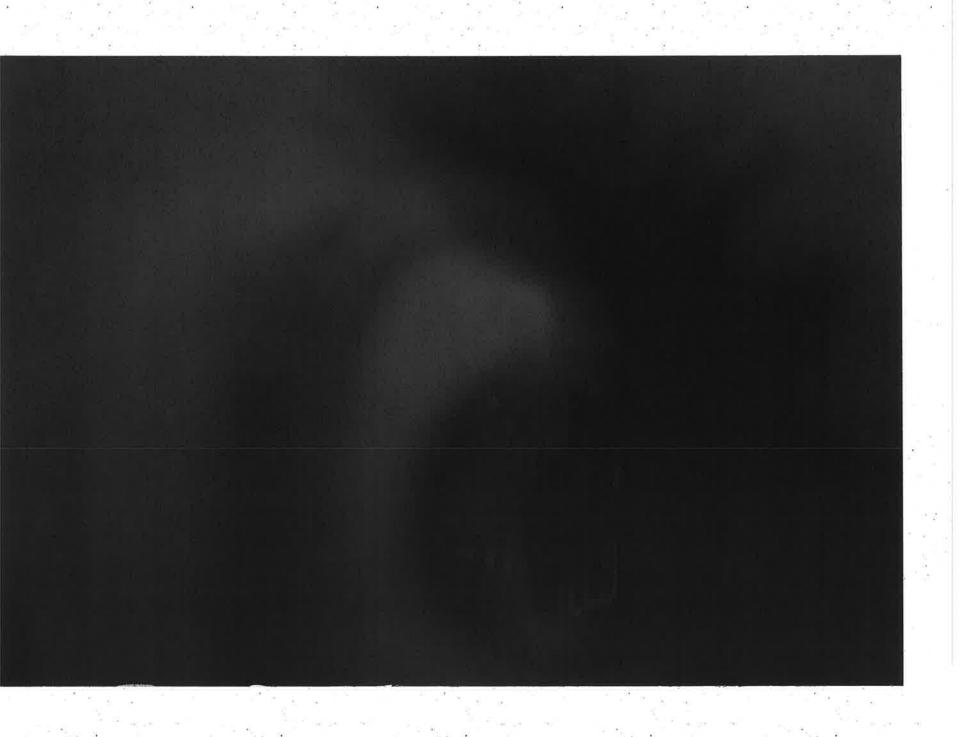
Appendix 7.1

In the original publication (Martens, 2004), no difference was made between 'failure to select' and 'failure to respond'. When writing this thesis, we wondered if it was possible to make a distinction between these two categories.

In 0 to 1.5% of all stimuli (relevant and irrelevant information), there was a 'failure to select' if observers were not able to develop any task related expectations (random condition). For the condition in which observers were able to develop expectations about the stimuli (predictable condition), distractors were not selected in 0.05% to 3.8% of the cases compared to 0% - 1.6% of the cases for the targets. Here we speak about cases since the percentage does not apply to the number of distractors but rather to the total number of cases (number of observers times the number of distractors). Even though one may claim that these percentages are low, it is striking to find that even when people have expectations about what will be relevant, this information is not always selected.

Despite the low occurrence of 'failure to select', we found a much higher occurrence of 'the failure to apprehend'. In those cases in which people had task related (but in some cases incorrect) expectations (predictable condition), 'the failure to apprehend' occurred in 58% to 67% of the unexpected cases, despite the fact that the 'failure to select' only occurred between 0 and 3.8% of the cases. Apparently under these task conditions, 'the failure to apprehend' is primarily the result of 'failure to respond' and not so much the result of 'failure to select'.

Our second experiment, described in this chapter, showed that in case of task related (but incorrect) expectations, there was a failure to respond in about 11 to 44% of the cases, whereas this was between 0 and 11% for the cases in which observers were not able to develop task related expectations. Even the responses that were provided (hits) suffered from expectations in case of unexpected but relevant information. For those observers that did generate a response, there was still a negative effect in terms of an increased response time for unexpected but relevant information. Under those circumstances, response times could be twice as high compared to the normal response times to expected and relevant information. Furthermore, response times to unexpected but relevant information were even higher than under circumstances in which observers did not have expectations and therefore already had higher response times to relevant information.

8

Expectations, glance duration and manual response: effect on detecting and ignoring stimuli[2]

[2]This chapter is based on the following submitted article: Martens, M.H. (submitted).
Expectations, glance duration and manual response: effect on detecting and ignoring stimuli.

8.1 Introduction

Detecting and responding to visual information that is relevant for our task at hand is a crucial part of task performance. However, in some conditions, people do not respond to relevant and clearly visible information. We refer to this phenomenon as 'the failure to apprehend'. 'The failure to apprehend' refers to a situation in which visual information presented to the observer is clearly visible once pointed out, is relevant for the task but there is no (or an incorrect) response. It is interesting to understand why this occurs. The main question is whether this is the result of the failure to visually select the information ('failure to select') or whether the information is selected (e.g. glanced at) but the processing of the information is not deep enough to enable a response ('failure to respond').

The most likely situations that induce 'the failure to apprehend' are situations in which only a small part of the available attentional resources is directed to the task at hand. In these situations, people perform their task fairly well, while maintaining resources available for other tasks or thoughts. This phenomenon is typically present in well-practised tasks or vigilance tasks. Vigilance tasks require sustained attention, being prolonged and continuous (Jerison, 1970; Warm, 1977). These tasks typically result in low task load (Jerison, 1970; Warm, 1977) or induce a low level of arousal (Parasuraman, 1984). During vigilance tasks, observers monitor targets that occur infrequently and the targets are clearly perceivable when the observer is alerted to them. Examples of typical vigilance tasks are inspecting individual items for classification of manufactured goods, or radar monitoring in an air traffic control centre (Wiener, 1984). The challenge for the operator is to maintain some level of alertness despite the low task load (Jerison, 1977). In vigilance tasks, operators are found to miss crucial information despite the fact that the targets are of high importance to national safety. What was considered to be shocking in the first vigilance tasks (e.g. Mackworth, 1948) was the fact that observers missed targets even when visually fixating them (Baker, 1960; Mackworth, Kaplan & Metlay, 1964).

Detection of relevant information also depends on expectations (Van der Hulst, Meijman & Rothengatter, 1999). Based on experience, people know where and when relevant information is likely to appear. Research on expert performance confirms this by showing that experts primarily focus attention on domain-specific stimuli whereas non-experts also pay attention to other stimuli. Experts in American football are faster in detecting changes in photographs related to football than novices (Werner & Thies, 2000). Chess masters have better immediate memory for chess-related information with brief exposures (De Groot, 1978; Chase & Simon, 1973a, 1973b), expert chess players are better in detecting changes related to the chess play than novices (Reingold, Charness, Pomplun & Stampe, 2001) and experienced drivers are better in detecting driving-relevant changes compared to non-driving task related

changes (Groff & Chaparro, 2003; Pearson & Schaefer, 2005). These results suggest that expertise, and possibly thereby expectations, guide perception.

Meyers and Rhoades (1978) illustrated the strength of expectations by showing that search for an object at a non-predictable location was much slower than search for an object at a likely location. Theeuwes (1991a) showed that expectancies about the location of the target (traffic signs) had an effect on the scanning behaviour (searching on the right side of the road where they are normally located). Martens (2004) found that with a predictable order of targets and distractors, participants glanced at targets longer than at distractors. These studies all imply that people direct their attention according to where relevant information is expected to be, resulting in an effective and economic search if these expectations are correct. This type of search is also referred to as 'top-down' and can be contrasted with search which is primarily 'bottom-up'. If visual selection is controlled by the properties of the stimulus field (e.g. salience by physical features), this is referred to as 'bottom-up'. If visual selection is controlled by intentions, goals, deliberate strategies and expectations of the observer, it is said to be 'top-down' (see Egeth & Yantis, 1997; Theeuwes, 1993, 1994; Eriksen & Hoffman, 1972; Posner, 1980; Yantis & Jonides, 1984; Yantis, 1996, 2000; Abrams & Jonides, 1988; Findlay, 1981; Fischer & Weber, 1993; Shepherd, Findlay & Hockey, 1986). Since in the aforementioned studies (Meyers & Rhoades, 1978; Theeuwes, 1991a; Martens, 2004) processing is based on expectations, it is said to be top-down. Top-down visual search can be so strong that observers have been found to ignore salient objects when these objects are irrelevant for their task (Theeuwes, 1990, 1991b). The nature of top-down effects on processing of scenes is thought to be the result of an interaction between incoming perceptual information and higher level memory representations, such as schemata (Theeuwes, 1992a). Schemata are general cognitive structures that help to organise perceptual information (e.g. Bartlett, 1932; Coren, Ward & Enns, 1994; Rumelhart, 1976). People use schemata to structure their world (Schank & Abelson, 1977), with a schema being a summary of all similar things in similar events. Schemata activate expectations about what things look like, how they behave, what type of objects are present in a scene, and how they are spatially related to each other (Biederman, 1981; Biederman, Mezzanotte & Rabinowitz, 1982; Hollingworth & Henderson, 1998; Taylor & Crocker, 1981). It is by means of these expectations that schemata guide information processing.

However, expertise or expectations may also introduce a perception fallacy that can have negative consequences. People may remember perceiving items that were not actually there, just because people expect them to be present. Alternatively, information conflicting with the expectations may be overwritten (Gale & Findlay, 1983), which may result in not perceiving this information. Consider the following

example of Sarter and Woods (1997). In the cockpit of highly automated aircraft, pilots failed to detect changes in an automation configuration when the automation took an unexpected action. Since this was not expected, it was not detected. Pilots also reported that they looked where they expected to find changes which may explain the detection failure. If observers only look where they expect to find information or changes, then there is the risk of missing important information. So if the expectations are correct, detection is rather effective and fast, but in case of incorrect expectations detection may be slow or even absent. Interestingly, Johnston and Hawley (1994) stress that even though schemata-driven perception is strong, the human system still remains alert for novel input. This indicates that even though new or unexpected information would not fit the schema, it can still be processed (but see Christie and Klein, 1996).

The focus of this study is 'the failure to apprehend', based on the notion that expectations guide visual search and responses. In an earlier study, Martens (2004) had participants identify targets amongst distractors in a dynamic computer simulated environment. The task of the participants was to click a mouse button for targets and ignore distractors. The purpose of the experiment was to assess the effects of expectations on eye glance duration and manual responses to targets and distractors. The results showed that in a predictable task environment, glances at distractors are shorter compared to glances at targets. The negative side effect of these expectations was shown in case of unexpected information. When an unexpected target appeared where a distractor was expected, participants either missed the target or responses were severely slowed.

The current experiment again addresses the effect of expectations on glance duration and manual responses to expected and unexpected information. A similar dynamic task environment was used, with two main differences compared to the former study. One difference relates to the type of distractors used and the other relates to unexpected information. The type of stimuli that Martens (2004) used were stimuli that either changed into a target or remained the same (by default being a distractor). This specific set-up could have resulted in the shorter glances at distractors in case of expectations. If people expect a stimulus to be a distractor they may not glance at the stimulus long enough to encounter the point of change, since they do not expect the stimulus to change. Therefore the current experiment used another definition of targets and distractors. A neutral stimulus was presented that either changed into a target or into a distractor at a certain point, possibly forcing participants to await that moment. The question was whether this set-up would also result in shorter glances at distractors (irrelevant information) compared to glances at targets (relevant information). The second difference concerned the unexpected information. Martens (2004) only introduced unexpected extra targets where participants expected a

distractor (requiring a response when one did not expect to give one). The current study also introduced unexpected extra distractors where participants expected a target (requiring participants to refrain from responding when one expected to respond). Missing information due to wrong expectations may lead to serious consequences, but false alarms may have serious consequences as well. An additional question was whether providing a second implicit cue about the identity of a stimulus (target/distractor) would help participants in correctly responding to the unexpected information. If this is indeed the case, additional information can be used to reduce the negative effects of expectations. In case of 'the failure to apprehend', we try to make a distinction between 'failure to select' (the information was not selected for further processing) and 'failure to respond' (the information was selected but processing was not deep enough to enable a response).

8.2 Method

8.2.1 Participants

In total 50 participants took part in the experiment. Participants were randomly assigned to one of five conditions for this between-participant design (10 participants per condition). Their ages ranged from 18 to 32 and both male and female Dutch participants were included. All participants reported to have good visual acuity. They were paid for their participation.

8.2.2 Task

The task environment was similar to the one used in Martens (2004). As is shown in Figure 8.1, the task environment consisted of a virtual grass field with a road, on which the participants had the illusion of moving forward. Along the side of the road (on the grass field), irrelevant objects were located, comparable to buildings and trees next to a road.
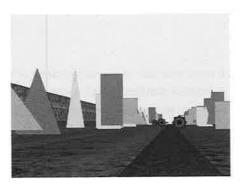

Figure 8.1 The task environment that was shown to participants, with a stimulus that just turned into a distractor.

From the horizon, a continuous flow of stimuli, formed by an asterisk, surrounded by two shapes (a square and a diamond) appeared. These stimuli became larger as the participants virtually moved through the environment with a continuous pre-set speed. If an object was 'close' to the participant, it would be on the right side of the road and finally disappear from the screen. Every 1.1 seconds, a stimulus disappeared from the screen. The task of the participants was to decide whether the closest (and thus largest) object was a target or a distractor. They were instructed to press the mouse button as soon as they detected that a stimulus changed into a target. A target was defined as a cross and a distractor as a plus sign. In order to avoid that participants would press the mouse button at fixed time intervals (every 2.2 seconds), some variation was introduced in the moment at which a stimulus changed. This also stimulated participants to really glance at the stimuli and follow them with the eyes. The stimulus, target and distractor set are shown in Figure 8.2.
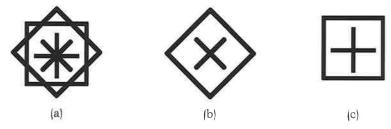

(a)   (b)   (c)

Figure 8.2 The stimulus as it appeared on the screen (a), either changing into a target (b) or a distractor (c).

A cross was surrounded by a diamond shape (Figure 8.2b) and a plus sign was surrounded by a square shape (Figure 8.2c). The target and distractor were presented in a predicable way, with one target always being followed by a distractor and vice versa. Participants were not instructed that the stimuli would have this predictable order of presentation.

8.2.3 Conditions
In total five conditions were included in the experiment, with ten participants per condition. Condition 1 (control condition) had a completely predictable order in which targets and distractors were presented, with a target being followed by a distractor and vice versa. Targets (crosses) were always accompanied by diamond shapes and distractors (plus signs) were always accompanied by squares. In condition 2, 3, 4 and 5, some irregularities were presented. The difference between these four conditions was the type of irregularity. In condition 2 and 3 (unexpected targets, UT), irregularities were introduced: a target could appear where normally a distractor would appear. In this case the order would be distractor – target – target

– target – distractor – target. Participants had to respond whereas they most likely did not expect to respond. In condition 2 (UT/CC = unexpected target/congruent conjunction) a congruent conjunction was shown, whereas in condition 3 (UT/IC = unexpected target/incongruent conjunction) an incongruent conjunction was shown. In condition 3, a target (cross) was surrounded by a square (incongruent conjunction) whereas normally targets were surrounded by diamond shapes. In condition 4 and 5 (unexpected distractors, UD), a distractor was shown when normally a target would appear. In this case the order would be distractor – distractor – distractor – target – distractor. Participants had to refrain from a response whereas they most likely expected to be responding. In condition 4 (UD/CC = unexpected distractor/ congruent conjunction) the unexpected distractor was accompanied by a congruent conjunction and in condition 5 (UD/IC = unexpected distractor/incongruent conjunction) this irregularity was surrounded by an incongruent conjunction (plus sign surrounded by diamond whereas normally plus signs were surrounded by squares). In condition 2 and 4 (congruent conjunction), participants actually had two cues whether something was a target or a distractor. In condition 3 and 5 (incongruent conjunction), participants had one cue and one (implicit) misleading cue. Participants did not receive any information about the surrounding shapes (implicit information). In all conditions, 2730 stimuli were presented (390 stimuli x 7 sessions with each session lasting 7 minutes). In condition 2, 3, 4 and 5, there were 5 irregularities in 2730 stimuli presentations. Note that the presentation of the remaining 2725 stimuli was the same over all conditions.

8.2.4 Apparatus

A corneal-pupil eye reflection tracking system (ISCAN) was built into an experimental configuration, suited for measuring eye movements. The processor sampled at 60 Hz. The eye's pupil and corneal reflection positions were calculated with 12-bit resolution. The infrared light source and the camera were located 0.35m in front of the right eye of a participant. Before the experiment could be started, the eye measurement system had to be adjusted to the right eye of the participant. A participant was seated in front of a computer screen with his/her head resting on a chin rest. This rest was located 0.97m from the screen.

The computer that was used to run the experiment was a dual processor Pentium III 866 MHz processor. The images were generated by an Evans & Sutherland SimFusion OpenSim 4000 and displayed on a 19" SVGA colour monitor. The display resolution was 1280x1024 with a high colour (32 bits) palette at 60 Hz. The computer that was used in order to generate the sessions and to start the task was a Pentium 166 processor, which was also used for storing the data during the experiment. The buttons of a mouse were used as response buttons (participants could click any of the three available buttons).

To record the comments participants made during the sessions, a microphone was attached to the chin rest. The idea was that it would be an instinctive response of participants to comment on the fact that they incorrectly pressed the mouse. They were specifically instructed to verbally respond if they noticed they made an error. A video camera recorded the sounds of the microphone in parallel to a graphic version of the session, which ran simultaneously with the session the participants saw, on a computer outside the experimental room.

8.2.5 Procedure

After reading the instructions, participants were seated in front of the monitor of the computer. Their head was resting in a chin rest, which was located 0.97m from the screen. A one minute preview of a session was shown prior to the experiment. Altogether, the experiment had seven sessions, with 390 stimuli each. Each session was 7 minutes long, with a short break in between sessions.

During the experiment, participants' eye movements were recorded, as well as the response time to the appearance of the target (or in case of a false alarm to a distractor). As already stated, voice recordings (verbal corrections of responses) were also made. Participants were instructed to respond as fast and accurately as possible and to verbally indicate errors. The object of this last measure was to give participants the opportunity to correct their initial response to an 'unexpected absence of a target' after they noticed the error. By using these recordings it was possible to separate the participants that did not notice the irregularity from the participants that did respond but noticed the incorrect response.

8.2.6 Statistical analysis

The dependent variables were the number of correct responses, glance duration, response time and the number of comments the participants made during the sessions (to verbally correct an incorrect response). Chi-square tests were conducted to compare the number of incorrect responses to the irregularities of the conditions with unexpected targets (misses) to the number of incorrect responses of the conditions with unexpected distractors (false alarms).

For the analysis of glance duration, the percentage of the total glance duration for a stimulus was used instead of glance duration in ms, the same procedure as was used by Martens (2004). The time that a participant glanced at the largest and closest stimulus was divided by the total time that this stimulus actually was the largest and closest stimulus. The percentage was defined as 100% if participants glanced at the stimulus as soon as it was the largest and closest stimulus (this would be after the preceding stimulus disappeared from the screen) and did this until it entirely disappeared from the screen. In order to get glance duration in ms, the percentage should be multiplied with 1100 (1.1 seconds).

ANOVA (analysis of variance) was used to analyse the effect of stimuli (target/distractor) on glance duration. Tukey HSD post-hoc tests were used to compare the duration of glances at irregularities with glances at surrounding targets. T-tests were used for comparing response times to irregularities to the mean response time to targets in the corresponding session. Also, a t-test analysed the effect of conjunction on the number of correct responses. Since the data analyses did not show clear effects of the conjunction, the data for condition 3 and 5 will not be described in further detail. If possible, data concerning the number of correct responses to the irregularity were analysed excluding and including verbally corrected responses. Because the data set was too large to analyse, each five separate sequential percentages of total glance duration were averaged for each participant when analysing data for an entire session.

8.3 Results

8.3.1 Percentage of total glance duration targets and distractors

In order to determine whether glances at expected relevant information (targets) were longer than glances at expected irrelevant information (distractors), the percentage of total glance duration for targets was compared to that for distractors. The detailed results are presented in Appendix 8.1. Every session, including the sessions with irregularities, showed significantly higher percentages of total glance duration for targets relative to that for distractors. Over all sessions, the percentage of total glance duration was 35.96% for distractors and 41.50% for targets.

8.3.2 Number of incorrect responses

The number of incorrect responses (misses or false alarms) to the irregularities were analysed. The detailed results are shown in Appendix 8.2. For all irregularities, quite many errors were made (on average 31% misses and 82% false alarms) compared to regular targets and distractors (on average 3% misses and 1% false alarms). For four out of five irregularities, the number of false alarms was larger than the number of misses. Since participants were instructed to speak out loud when they made an error, incorrect answers that were verbally corrected could be analysed as correct as well. This allowed a better understanding of whether the irregularity was detected or not. In case of verbally corrected data, the response was incorrect (one responded whereas one should not have responded) but we recorded that the error was noticed. This allowed us to analyse incorrect responses and incorrect responses what were verbally corrected. When treating verbally corrected data as correct responses, the difference between misses and false alarms was smaller, with two out of five irregularities resulting in more false alarms than in misses. These results are also shown in Appendix 8.2.

8.3.3 Response times

The response time to the unexpected target and the response times to the five targets before and the five targets after the irregularity were compared to the individual mean response time (calculated per participant) of each condition in each session. Detailed results are shown in Appendix 8.3.

For condition 2 (unexpected target), response times are for correct answers (hits), whereas for condition 4 (unexpected distractor), response times are for incorrect answers (false alarms). For all correct responses to unexpected targets (hits), the response time to the irregularity was significantly higher than the mean response times to targets. This means that correct responses suffered from a delay in response time. As an example, Session 1 of condition 2 (UT/CC) had significantly higher response times for the unexpected target and the first target after the irregularity were significantly higher than the mean response time in Session 1 [t(9) = 7.02; p < 0.0001 and t(9) = 2.36; p < 0.05 respectively] (see Figure 8.3).
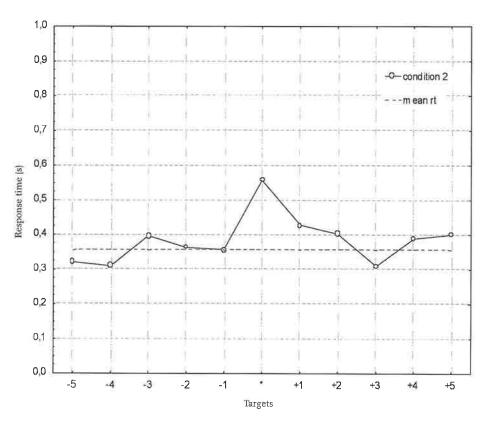

Figure 8.3 The response times to the unexpected target (*) and 10 targets around it of condition 2 in Session 1.

For most of the irregularities (unexpected targets and unexpected distractors), response times to first few targets after the irregularity were increased. These results are presented in Appendix 8.4.

For all incorrect responses to unexpected distractors (false alarms), the response time to the irregularity was equal or lower than the mean response time to targets This means that participants pressed as quickly as they normally did when responding to targets without any hesitation. As an example, the response times for Session 1 condition 4 (UD/CC) around the irregularity are presented in Figure 8.4. The response time to the irregularity was as fast as the mean response time. The first target after the irregularity showed higher response times compared to the mean response time [t(9) = 4.01; p < 0.01].

The largest delay in response times to the irregularity compared to the mean response time was found for Session 3 in condition 3 (UT/IC) [t(6) = 6.49; p < 0.0001]. There was also a higher response time to the first target after the irregularity [t(6) = 7.20; p < 0.0001]. These results are shown in Figure 8.5.
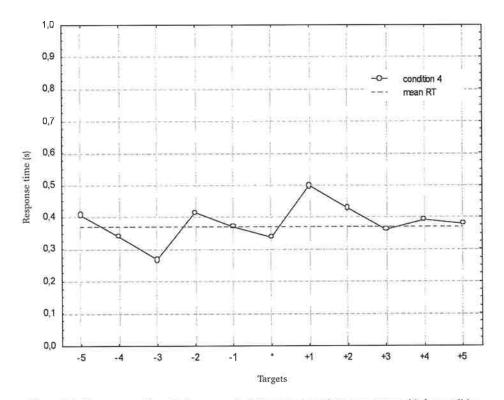

Figure 8.4 The response times to the unexpected distractor (*) and 10 targets around it for condition 4 in Session 1.
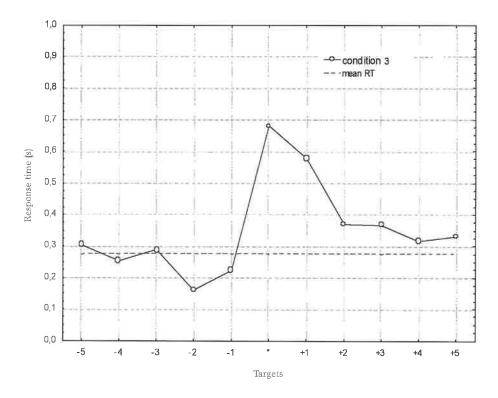
Figure 8.5 The response times to the unexpected target (*) and the ten targets around it of condition 3 in Session 3.

8.3.4 Percentage of total glance duration and irregularities

First of all, it must be mentioned that all irregularities were selected by means of eye glances. The occurrence of 'the failure to apprehend' in this experiment is therefore not the result of a 'failure to select' but rather to a 'failure to respond'.

The percentage of total glance duration was analysed around the presentation of the irregularity. If glance duration increased around this irregularity, this could indicate implicit detection. Interesting is also to determine whether correct responses were accompanied by longer glances. In most cases, glances at irregularities were equally long as glances at the stimuli surrounding the irregularity. For unexpected targets (condition 2), the percentage of total glance duration was comparable to that of the surrounding distractors (participants expected a distractor and glanced at the irregularity as short as at a distractor). This was also the case if only glance durations for correct responses are included in the analysis. In condition 2, there were two irregularities that showed a significantly different glance duration compared to surrounding distractors (in one case longer and in one case shorter). Excluding incorrect

responses showed that longer glances are not related to correct responses, nor are shorter glances related to incorrect responses.

For unexpected distractors (condition 4) glances were in most cases equally long as glances at surrounding targets (participants expected a target and glanced at the irregularity as long as at a target). There was no difference in glance duration between correct and incorrect responses. For those sessions in which longer or shorter glances were found around the irregularity, this effect disappeared when excluding data of incorrect responses. Again here, shorter glances were not associated with incorrect responses, nor were longer glances associated with correct responses.

8.4 Conclusions

8.4.1 Number of correct responses

A relatively high number of errors was made when irregularities were presented. In case of unexpected information, the costs in terms of errors are high. For four out of five irregularities, more false alarms than misses were found. One possible explanation can be found in the method for assessing responses. If initially someone does not respond to the unexpected target, but realises this in time, (s)he can still respond. Although the response is rather late, it is still counted as 'correct' (hit). Once someone responds to the unexpected distractor, but realises the incorrect response, it is already too late since the response was already recorded as an 'incorrect' response (false alarm). Even though this explanation is feasible, it cannot explain all results. Even when incorrect responses (false alarms) that are detected by participants (with participants verbally correcting their error) are treated as 'correct responses', there is still a higher number of incorrect responses for the unexpected distractor compared to the unexpected target (even though the difference here is smaller). The expectations about the presence of targets seem to generate an almost automatic (incorrect) response, which may or may not be noticed. Generally speaking, there were equal or less verbal corrections than there were incorrect responses without verbal correction. So in most cases there is an incorrect response without people detecting the error. In some cases people detect the error but are not able to stop the initiated response in time (resulting in a false alarm with a verbal correction).

8.4.2 Response times

Besides many incorrect responses, there are also other costs involved with incorrect expectations. Those participants that did respond to the unexpected target (hit) had higher response times than the response times of the expected targets in the corresponding session. This effect was present in all sessions. In some cases, the response times to targets presented directly after the irregularity were higher as well.

Response times to unexpected distractors (note that responding was incorrect (false alarm)) did not differ from the mean response time to targets in the corresponding session. This shows that participants responded as fast as they normally would to a target without any hesitation. This was the case for all sessions. The fact that these response times were not longer than the response times to other targets corresponds with the idea that participants responded to this item as a target since they expected a target. In some cases, the response times to targets presented directly after this unexpected distractor were higher, indicating there may have been some late detection of the irregularity.

8.4.3 Percentage of total glance duration

One should keep in mind that due to the nature of the experiment, there was no need to glance at targets longer or shorter than at distractors. Since the set-up in the current experiment required participants to glance at a stimulus until it either changed into a target or into a distractor, there was no a priori reason to find a difference in glance duration between targets and distractors. Therefore, a difference between glance duration would be a difference between expectations on forehand about the nature of the stimulus.

All irregularities were selected by means of glances. In case of 'the failure to apprehend', the information was selected but apparently not processed to a deep extent to enable a correct response. All sessions showed significantly longer glances at targets than at distractors. These results confirm the results of Martens (2004), showing that participants spend more time glancing at information they expect to be relevant than glancing at information that is expected to be irrelevant. The irregularities did not change glance strategies, since participants remained to glance at targets longer than they did at distractors after an irregularity.

Concerning glance duration around the irregularities, there is no evidence that correctly identified irregularities were accompanied by longer glances. For the unexpected targets (participants expected a distractor), glances were as short as the glances at surrounding distractors. This was the case even for those cases in which people correctly responded by pressing the mouse button. For the unexpected distractors (participants expected a target), glances were as long as the glances at surrounding targets, but nevertheless this led to many incorrect responses. Glances at the irregularity for those who responded correctly were also not longer than glances at surrounding targets.

8.5 Discussion and practical implications

The current experiment replicates the findings of Martens (2004). People glance at information they consider to be relevant for a longer period of time than they glance at information they consider to be irrelevant, even though they glance at both types of information. Despite the different character of the stimuli and the fact that in the current experiment, the stimulus was not by default a distractor, similar results were found. This confirms the generalisability of the effect. Expectations make people spend more time glancing at information they consider to be relevant. However, if information is not in line with expectations, there are costs involved. These costs can be threefold; there is 'the failure to apprehend' (there is a 'failure to select' or a 'failure to respond' despite the fact that the information is selected by means of glances), response times are relatively high or one responds when a response should have withheld. In the current study, 'the failure to apprehend' is not the result of a 'failure to select' but rather a 'failure to respond', most likely due to insufficiently deep processing. Apparently it is harder to inhibit a response to 'expected to be relevant information' than it is to respond to 'expected to be irrelevant information'. This may be related to the fact that one glances at 'expected to be relevant information' longer than one glances at 'expected to be irrelevant information'. However in both conditions, quite some errors were made (even with longer glances). Misses occur between 0 and 70% of the cases and false alarms between 60 and 100%. Verbally corrected data decrease the percentage of false alarms to between 30% to 70%, although one has to realise that in real-life tasks, it is often not possible to correct an initiated action in time. The maximum mean increase in response time was around 420 ms, being twice as high as the mean response time of that session and that condition. Individual data showed even larger effects. Compared to incorrect responses, correct responses were not found to be accompanied by longer glances at the irregularities. Adding an extra implicit cue to distinguish targets from distractors did not result in better responses. Apparently more is needed to break through these expectations.

These costs of expectations (high percentage of misses, false alarms and high response times) may have major implications for real life tasks. Imagine an air traffic controller. While looking at a visual display with incoming airplanes (s)he may fail to detect or respond very late to an unexpected event. Or an operator who has to press a button every time a product fulfills quality requirements, pressing it more or less automatically with unqualified products ending up together with qualified products (imagine the consequences for medication). It is therefore recommended to conduct more research regarding this difference in real life situations, in which participants have strong expectations about relevant and irrelevant information.

Appendix 8.1

Percentage total glance duration for targets and distractors.

Session	Effect	Targets	Distractors
Session 1	$F(1,45) = 111.45; p < 0.0001$	38.62%	35.55%
Session 2	$F(1,45) = 27.78; p < 0.0001$	41.58%	35.98%
Session 3	$F(1,45) = 17.81; p < 0.0001$	41.79%	36.15%
Session 4	$F(1,45) = 21.30; p < 0.0001$	41.77%	36.24%
Session 5	$F(1,44) = 15.67; p < 0.001$	41.78%	35.31%
Session 6	$F(1,45) = 10.48; p < 0.01$	41.76%	36.22%
Session 7	$F(1,45) = 12.74; p < 0.001$	42.28%	36.24%

Appendix 8.2

Number of incorrect responses to irregularities.

Number of incorrect responses without taking verbal corrections into account (n.s. is not significant)

Irregularity	Effect	Misses (cond 2)	False alarms (cond 4)
Session 1	$p < 0.0001$	0	8
Session 3	$p < 0.001$	1	10
Session 5 - 1	n.s.	7	9
Session 5 - 2	$p < 0.0001$	4	7
Session 7	$p < 0.001$	4	7

Number of incorrect responses treating verbally corrected errors as correct responses (n.s. is not significant)

Irregularity	Effect	Misses (cond 2)	False alarms (cond 4)
Session 1	$p < 0.01$	0	6
Session 3	$p < 0.01$	1	6
Session 5 - 1	n.s.	7	4
Session 5 - 2	n.s.	4	4
Session 7	n.s.	4	3

Appendix 8.3

Response times to irregularities in various sessions and various conditions.
Note that in condition 2, responding is correct (hit), in condition 4, responding
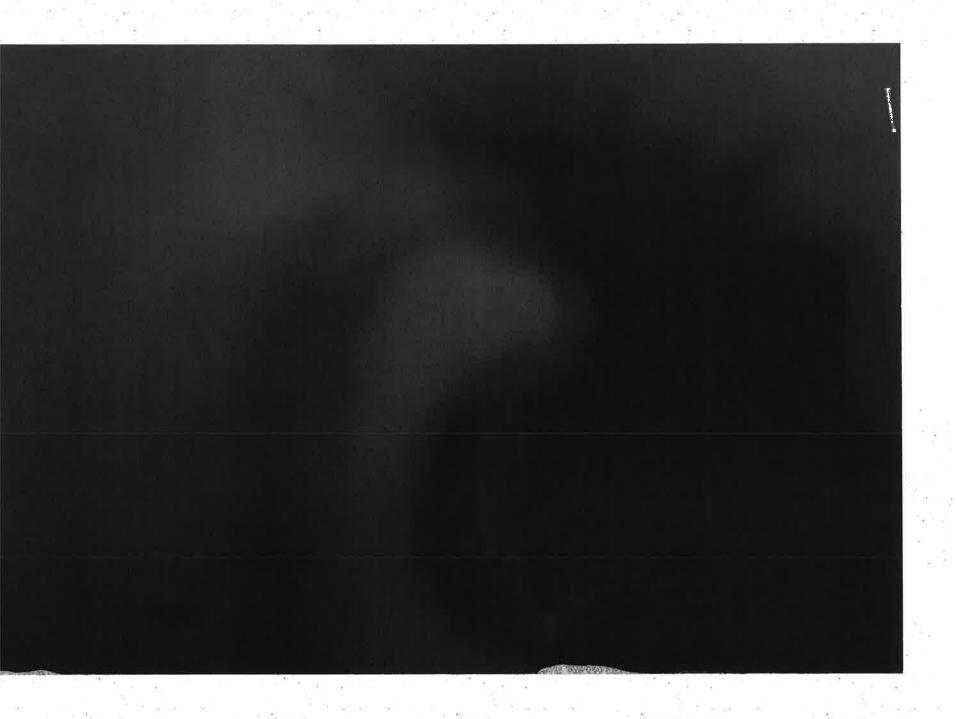is incorrect (false alarm).

Session	Condition	Effect	Mean RT	RT to irregularity
	Cond 2 (hit)	t(9) = 7.02; p<0.0001	0.355	0.558
	Cond 4 (false alarm)	n.s.	0.360	0.338
3	Cond 2 (hit)	t(9) = 7.61; p<0.0001	0.297	0.623
	Cond 4 (false alarm)	n.s	0.294	0.263
5-1	Cond 2 (hit)	t(9) = 3.90; p<0.01	0.266	0.470
	Cond 4 (false alarm)	n.s.	0.290	0.259
5-2	Cond 2 (hit)	t(9) = 6.47; p<0.0001	0.266	0.614
	Cond 4 (false alarm)	n.s.	0.290	0.246
7	Cond 2 (hit)	t(9) = 13.31; p<0.0001	0.269	0.537
	Cond 4 (false alarm)	n.s.	0.282	0.290

Appendix 8.4

Higher response times for targets presented after the irregularity.

Session	Cond.	Effect of targets after irregularity				
		1	2	3	4	5
1	Cond 2	$t(9) = 2.36$; $p < 0.05$	n.s.	n.s.	n.s.	n.s.
	Cond 4	$t(9) = 4.01$; $p < 0.01$	n.s.	n.s.	n.s.	n.s.
3	Cond 2	$t(9) = 5.35$; $p < 0.001$	$t(9) = 3.12$; $p < 0.01$	n.s.	n.s.	n.s
	Cond 4	n.s.	n.s.	n.s.	n.s.	n.s.
5-1	Cond 2	$t(9) = 4.44$; $p < 0.01$	n.s.	n.s.	n.s.	n.s.
	Cond 4	n.s.	$t(8) = 7.08$; $p < 0.0001$	$t(8) = 8.50$; $p < 0.0001$	n.s.	n.s.
5-2	Cond 2	$t(9) = 3.31$; $p < 0.01$	n.s.	$t(9) = 2.57$; $p < 0.05$	n.s.	n.s.
	Cond 4	$t(6) = 3.01$; $p < 0.05$	n.s.	n.s.	n.s.	n.s.
7	Cond 2	$t(9) = 5.03$; $p < 0.001$	n.s.	$t(9) = 2.40$; $p < 0.05$	$t(9) = 3.10$; $p < 0.05$	$t(9) = 5.58$; $p < 0.001$
	Cond 4	n.s.	n.s.	$t(3) = 4.73$; $p < 0.05$	n.s.	n.s.

9

Do familiarity and expectations change perception? Drivers' glances and response to changes[3]

9.1 Introduction

If a task is well practised, only a small part of the available attentional resources has to be directed to that task. This is also the case for the driving task in which novice drivers have to invest a lot of effort into driving, but after some experience less attention has to be paid to the task itself. The driving task is often decribed in terms of the three different performance levels distinguished by Rasmussen (1986). Although Rasmussen's model is a general task performance model, applicable to different sorts of tasks, it fits the driving task well (a.o. Hoedemaeker, 1999; Kuge, Yamamura, Shimoyama & Liu, 1998; Hollnagel, Nåbo & Lau, 2003). The three levels of behaviour that Rasmussen distinguishes are knowledge-based, rule-based and skill-based. Knowledge-based behaviour is applied in novel situations or at new locations and it represents a more advanced level of reasoning. It is the most demanding level of the three. An example in the driving context is a novice driver who still has to think about how to shift gear or an experienced driver who is driving in a city centre he has never been before. Rule-based behaviour is characterised by the use of rules and procedures to select a course of action in a familiar situation. The rules can be a set of instructions, e.g. if..... than...., acquired by a person through experience or provided by another person. An example in the driving context is giving priority to other road users, where drivers have learned that in the presence of specific traffic signs and road markings they have to give priority. Skill-based behaviour represents a type of behaviour that requires very little attention and does not allow conscious control to perform or execute an action. An example is an experienced driver steering the car between the road markings. The driver does not have to think about his task and small deviations in lateral position automatically trigger a steering response. Skill-based behaviour is shown when a task is highly trained.

In case of skill-based behaviour, for instance in case of experienced drivers, there is strong top-down control, with expectations of the driver guiding the gaze direction. In static non-driving surroundings Meyers and Rhoades (1978) investigated the effect of expectancy on visual scan patterns and showed that searching for an object at an unexpected location was much slower than searching for an object at a likely location. This implies that participants look where they expect relevant information to be, resulting in an effective search if these expectations are correct. In abstract laboratory experiments, Martens (2004) and Martens and Slegers (2002) showed that people fail to notice unexpected information or show increased response times to unexpected information. In the driving context, several studies point to expectation as a crucial factor influencing reaction times (Green, 2000; Evans, 2004; Rumar, 1990). Theeuwes (1992c) investigated the balance between top-down (active) visual search (ruled by expectations) and data-driven search (ruled by the object properties) in the driving context. In the Theeuwes study (1992c), participants watched a video

of an approach of an intersection while searching for a specific traffic sign that was either located at an expected or an unexpected location. The results showed that eye movements of experienced drivers were first directed at expected locations, leading to a delay in response time for targets at unexpected locations. The major advantage of using eye movements as a dependent variable is that they are fairly involuntary if participants are not instructed to search for specific items in the environment (Bhise & Rockwell, 1973) and they indicate the goals of the observer and possibly the area of interest (Liu, 1999; Stark & Ellis, 1981). This makes it a valuable tool for exploring the effect of expectation on visual information perception. Martens (2004) controlled expectations by designing an experiment in which expectations were built up inside the experiment. She showed in an abstract dynamic environment that people spend more time fixating targets they expect to be relevant. This fixation pattern results from sufficient practice with the task (skill-based behaviour). Unexpected information is either missed or responses are slow (even slower than when one does not have any expectations).

This means that especially in a road environment that is highly predictable (for instance because he or she has driven the road numerous times) the experienced driver will have strong expectations about what will happen, which will guide his visual scanning. The expectations are assumed to guide visual search, with strong top-down control.

This scanning according to expectations may appear to be a very efficient process. However, it may also bear risks. What if something unexpected happens that does not correspond to the expectations? It could be that the driver either notices this information since the unexpected is conspicuous, or would the driver miss this crucial information because it was not expected?

Most visual search experiments use predefined search targets, whereas in driving there are no specific predefined search targets. Few studies have examined visual search in a dynamic familiar environment without predefined search targets while controlling the expectations. The questions addressed in this study relate specifically to the driving task and to visual search without predefined targets while controlling expectations. The first hypothesis of the study is that drivers spend less time glancing at traffic signs if they are being exposed to the same route numerous times due to developed expectations. The second hypothesis is that after driving a road numerous times, drivers respond less adequately to a change in the traffic situation than people that did not encounter this road before.

9.2 Method

A virtual driving task in a low-cost driving simulator was used since this allowed changing the road environment rather easily compared to a field experiment. The virtual road consisted of an 11 km long combined rural (9 km) and urban (2 km) road. Participants were seated in front of a computer monitor and were asked to drive a simulated road, using a steering wheel, gas and braking pedal (see Figure 9.1).

Figure 9.1 The task environment of the experiment, with a participant driving through the virtual environment, wearing the eye movement equipment.

The road contained two intersections, 3 curves and 10 traffic signs along the route (see Appendix 9.2 for a list of the traffic signs displayed). Trees, houses, opposing traffic and parked cars were included in the database to make it more realistic. While people were driving the route, their glance direction was recorded and recorded in the overall scene. This allowed the analysis of glance duration and glance frequency to the traffic signs.

9.2.1 Participants

Thirty-six participants took part in the experiment. Their ages varied from 21 to 46 and both male and female Dutch drivers were included. Participants had their driving licence for at least 3 years and drove over 5000 km/year.

9.2.2 Conditions

The thirty-six participants were randomly assigned to one of 3 conditions. The 3 conditions are also explained in Table 9.1.

Table 9.1 Overview of the type of drives for the 3 Conditions, in chronological order.

Condition drives	Day 1 1 2 3 4 5	Day 2 1 2 3 4 5	Day 3 1 2 3 4 5	Day 4 1 2 3 4 5	Day 5 1 2 3 4 5
1st Control	0 3				
2nd Control	0 2 4				
Experimental	0 1 1 1 1	1 1 1 1 1	1 1 1 1 1	1 1 1 1 1	1 1 1 2 3

0 = practice drive

1 = driving road 1 (last intersection: having priority)

2 = driving road 2 (last intersection: having to yield)

3 = road recognition test while driving road 1

4 = road recognition test while driving road 2

In the experimental condition 12 participants drove the same road 24 times on 5 successive days. Monday through thursday, 5 successive drives were made and on the fifth day, only four drives were made. Twenty-three drives were made with the participants having the right of way at both intersections. In drive 24 there was a change in priority situation at the second (and last) intersection. The changed situation was indicated by a different traffic sign (the Dutch priority ⚠ was replaced by the Dutch yield sign ▽) and by priority road markings ▼▼▼▼▼ on the road (see Figure 9.2).

The change was introduced in the 24th instead of the 25th drive since participants may have been expecting something on their last drive. After this 24th drive, participants had to perform the traffic sign recognition test. In this test, participants slowly drove the road one more time while the experimenter indicated the locations where traffic signs used to be present on the former 24 drives. Participants were asked to indicate what traffic sign had been present there by selecting the sign out of a list of 20 general Dutch traffic signs printed on a paper (see Appendix 9.1). This test was included in order to test the level of expectations regarding the traffic signs shown along the route and to test whether participants could explicitly report the changed
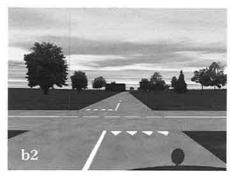
Figure 9.2 The last intersection that was changed into a yield situation for the experimental condition. The sign shown in Figure 9.2a, meaning you have the priority over the crossing road, was replaced by the sign, shown in Figure 9.2b1, meaning yield to road users on the crossing road. Shark teeth, shown in Figure 9.2b2 (priority road markings, ▼ ▼ ▼ ▼ ▼ were placed to confirm the necessity to yield). The indication for having the priority or having to yield was done according to the Dutch guidelines for intersections.

sign. In a field and a laboratory experiment, MacDonald and Hoffman (1991) found that the most dominant influence on correctly reporting a road sign was the probability of drivers having to make an overt response related to the sign information, or the so called action potential. The action potential for the changed sign was clearly high. Although the normal recognition rate for passed signs is low (e.g. Shinar & Drory, 1983; Johansson & Rumar, 1966; Johansson & Backlund, 1970; Milosevis & Gajic, 1986) the traffic sign recognition test was expected to be sensitive since the experimental condition drove the road 24 times before performing the test.

In the first control condition 12 participants did not make any experimental drives, but just performed the traffic sign recognition test. The condition allowed us to test how predictable the traffic signs were even if people had not previously been exposed to the road environment.

In the second control condition 12 participants drove the road only once in order to record glances and driving speed of people that did not yet have any expectations based on prior experience. In this condition the last intersection was an intersection where they had to give the right-of-way (similar to drive 24 of the experimental condition). After this drive people also performed the traffic sign recognition test.

All participants reported to have good visual acuity and did not wear glasses or lenses during normal driving. They were paid for their participation.

9.2.3 Apparatus

A pupil/cornea reflection eye tracking system (ISCAN) was used to measure the glance direction of the participant. This was done by illuminating the left eye with an infrared source. A camera obtained a clear image of the eye by using an infrared pass filter to identify the dark image area of the pupil. Another camera mounted slightly below the left eye recorded the participant's field of view. The eye's pupil and corneal reflection positions were calculated with a sample frequency of 120 Hz. The camera that recorded the participant's field of view was connected with a Panasonic VCR. The camera image with the super-imposed glances was recorded on VHS tapes for later analysis. The cameras and the infrared source were built into a specially designed cap (also see Figure 9.1). During the experiment participants could move their heads like they would normally do while driving.

The computer used for running the experiment was a dual Pentium 3 processor running at 866 MHz. This computer was also used for storing the data obtained during the experiment. The images were generated on an Evans and Sutherland SimFusion OpenSim 4000 and displayed on a 21″ SVGA Monitor. The monitor's resolution was 1280x1024 with high color palette (32 Bits) and a refresh rate of 60 Hz. A Logitech force feedback steering wheel and pedals were used as input devices. There was one braking pedal and one gas pedal (automatic gear). The speed of the car was shown on the lower part of the monitor for the participant and was saved to the computer's hard disk. Participants were seated about 1m in front of the screen.

9.2.4 Task

The task of participants was to drive as they normally would on this type of road in real life. Participants in the experimental condition (24 drives over 5 days) were asked to pretend that this was their daily drive home. The official speed limit was 80 km/h with a speed limit of 50 km/h in the urban area (2 km of length). No mirrors were present, but this did not cause a limitation in driving since participants did not make any turns or did not overtake. Objects alongside the road were trees, different

types of houses, parked cars and traffic signs. While driving on the road participants encountered opposing traffic without any lead vehicles.

9.2.5 Procedure

Before the actual experiment started, participants received a written and a verbal instruction that explained their task and the procedure. After this participants were seated in front of the computer monitor (one participant at a time) and the controls (steering wheel, gas and braking pedal, simulating an automatic gearbox) were demonstrated. The eye movement equipment was calibrated by the experimenter with the participants' heads on a chin rest. After the system had been calibrated participants were allowed to freely move their heads and made a practice drive on an empty road during 2 minutes to get used to the controls.

After every drive participants received a 30-second break. The last task for all participants was the traffic sign recognition task.

9.2.6 Statistical analysis

The calibration of the eye movement equipment before the start of the experiment allowed the calculation of the actual glance direction within a scene. Video images, showing the dynamic road scene, were recorded via the camera attached to the baseball cap and a cross, superimposed in the scene, indicated the glance direction. In this study, the term 'glance' indicates what someone gazes at, irrespective of whether this is fixated, fixated interrupted with saccades while gazing at the same object or whether the gaze is following a moving object. The analysis of these glance data was done by slow-playing the video with a reduction factor of 5 (5 times slower than normal playing speed). Every time the cross (glance) was within a range of 0.5 cm around a traffic sign within the area between 250 and 0 meter in front of the traffic sign (at this distance the traffic signs was clearly visible and readable) this was recorded to be a glance. The acquisition of glances was done manually. Other experiments (see Chapter 10) were already performed in real life traffic without the possibility to automatically acquire these data (due to the lack of control over the environment it had to be done from video). In order to compare results between this lab task and the real life experiments, the data acquisition was also done manually. For the assessment of glance duration, 10 traffic signs were selected and are listed in Appendix 9.2.

An analysis of variance (ANOVA) was used to analyse the total glance duration (which was a summation of the glance duration for all glances) per traffic sign and the mean driving speed per selected road section (the selected road sections are listed in Appendix 9.3). Fisher (1992) claimed that the true measure of sign

effectiveness is not sign recall, recognition or naming per se but rather the extent to which, in operational terms, sign content affects drivers' preparedness for action and subsequent responsiveness to events. Also, Häkkinen (1965), Scremec (1973) and Summala and Hietamäki (1984) assessed the effect of traffic signs on driver behaviour by measuring vehicle speed changes at predetermined locations close to the road sign. Since the results of glance frequency were similar to the results of total glance duration these results will not be discussed separately.

In order to analyse whether the duration of glances at traffic signs changed with exposure, only data from the experimental condition were analysed (this was the only group with numerous exposure). Since on the last day participants only drove 4 drives instead of 5 (a change in the very last drive might be too obvious, so the drive before that was chosen to be changed) no straightforward analysis with the factors Day (5 levels) and Drive (5 levels) could be performed. Therefore, data with 10 Traffic Signs, 4 Days and 5 Drives, or with 10 Traffic Signs, 5 Days and 4 Drives will be taken together in the analyses. Days and Drives were maintained as separate factors (instead of 24 drives) since it was speculated that the first drive on the next day would again lead to somewhat longer glances than the last drive on the day before. The probability of a Type I error was maintained at 0.05 for all subsequent analyses.

9.3 Results

9.3.1 Glance duration

Effect of familiarity
In order to analyse the effect of familiarity, glance duration was analysed for the first 4 Days and 5 Drives. A main effect was found for Day [$F_{(3, 33)}$ = 5.61, $p < 0.01$] indicating a decrease in glance duration at traffic signs with increasing number of days. The interaction between Day and Drive [$F_{(12, 132)}$ = 2.50, $p < 0.01$] showed that the largest decrease per drive was found on Day 1. This interaction is shown in Figure 9.3.

The interaction between Day and Traffic Sign [$F_{(27, 297)}$ = 1.73, $p < 0.05$] is shown in Figure 9.4, showing that the decrease in glance duration over days may differ from sign to sign.

The results also hold if 4 Drives and 5 Days are included in the analysis. There was no initial difference in traffic sign glance duration between the second control condition and the first drive of the experimental condition [$F_{(1,22)}$ = 0.12, $p < 0.73$].
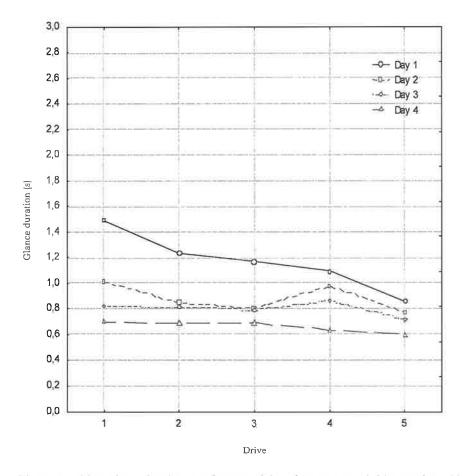
Figure 9.3 Mean glance duration as a function of day of testing (4) and drive number within each day (5).

Note that traffic sign 10 was different between these conditions, indicating 'Yield' in the second control condition and indicating 'Priority' in the experimental condition. When comparing glance duration on the last drive of the experimental condition (with the changed traffic sign but after numerous exposure to the road) with glance duration on the first drive of the second control condition (the same traffic sign but here it was the first time people drove the road), a main effect of Condition [$F_{(1,22)}$ = 25.75, $p < 0.01$] showed that the experimental condition had significantly shorter traffic sign glances than the second control condition (0.72s compared to 1.32s). This indicates that familiarity leads to shorter glances at traffic signs (not only within participants as was shown within one group but also between participants).
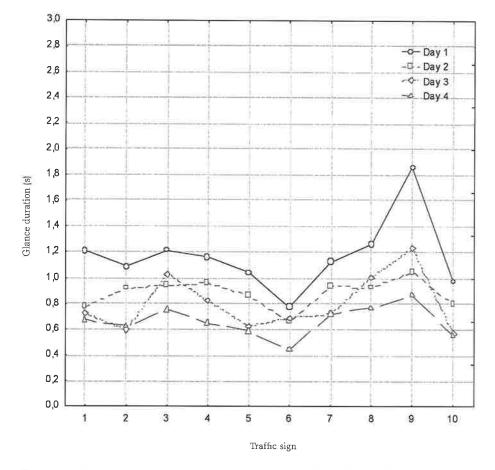
Figure 9.4 Mean glance duration per traffic sign as a function of day of testing (4).

Effect of change in priority situation

In the last drive of the experimental condition, the priority situation was changed. This included a change in traffic sign 10 and the presence of priority road markings. In order to assess possible effects on glance duration, glance duration for traffic sign 10 was compared to glance duration for traffic sign 1 (being the same traffic sign on 23 drives but being different on drive 24 (drive 4 day 5). One may assume that if participants noticed the change in traffic sign the glance would be longer. Literature has shown that first pass glance durations are longer for semantically informative (i.e. inconsistent) objects (Loftus & Mackworth, 1978) and that first pass glance duration is correlated with the rated likelihood of that object in the scene, with longer glances at objects that were less likely to be found in a particular scene (Friedman, 1979).

Henderson, Weeks and Hollingworth (1999) found that total fixation duration was longer for semantically informative than for uninformative objects and in reading it is widely reported that unfamiliar words require longer fixation durations than common words (Rayner and Pollatsek, 1989). The explanation for this is that an unfamiliar word requires more processing and within certain limitations, the measure of fixation duration is considered to reflect object identification time (Henderson, Pollatsek & Rayner, 1987; Underwood & Everatt, 1992).

A t-test for dependent samples did not show a significant difference between glance duration in Drive 3 (Day 5) and Drive 4 (Day 5) for the changed traffic sign [t(11) = 0.25, p < 0.81]. There was also no significant difference between the glance
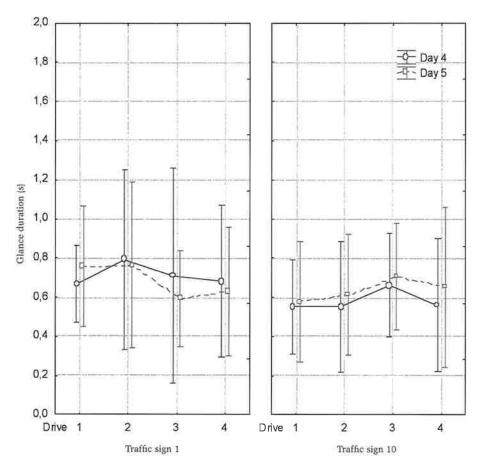
Figure 9.5 Mean glance duration for traffic sign 1 and traffic sign 10 as a function of drive number within the last two days (day 4 and 5). Traffic sign 1 was the same as traffic sign 10, with the only difference that traffic sign 10 changed on day 5 on drive 4. The bars indicate the standard error.

duration in Drive 3 (Day 5) and Drive 4 (Day 5) for traffic sign 1 [t(11) = 0.24, p < 0.81], being the same traffic sign as traffic sign 10 during 23 drives. In drive 24, traffic sign 1 and traffic sign 10 were different since traffic sign 10 changed into a yield sign. Figure 9.5 shows the glance duration for those two signs on the last 2 days. The figure shows that even though the traffic sign changed people did not spend more time glancing at that sign.

As an illustration, glance duration for the 10 traffic signs in drive 1 for the second control condition, in drive 1 for the experimental condition and in drive 24 for the experimental condition are presented in Figure 9.6.
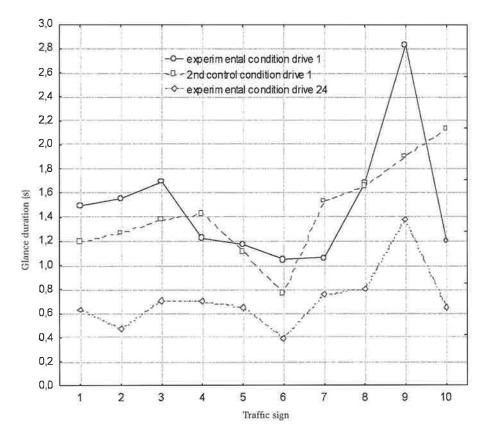
Figure 9.6 Mean glance duration at traffic signs for the first drive of the experimental condition, the first drive of the second control condition and the 24th drive of the experimental condition. Note that traffic sign 10 is different between 'experimental condition drive 1' (participants have priority) and '2nd control condition drive 1' and 'experimental condition drive 24' (participants have to give priority).

Twenty-five percent of the participants in the experimental condition (3 out of 12) did not glance at traffic sign 10 whereas this was 8% (1 out of 12) for the 2nd control condition. Note however that even if participants did not glance at the sign, they still might have seen the priority road markings. It seems plausible that the shorter glances for the experimental condition, found in general in drive 24, also led to the increased occurrence of 'the failure to apprehend'. Compared to drive 1 in the experimental condition, the curve follows that same pattern in drive 24 as in drive 1. However, in drive 24, traffic sign 10 was changed. In the 2nd experimental condition (drive 1), there are relatively long glances at traffic sign 10.

9.3.2 Driving speed

Effect of familiarity

Besides glance duration, driving speed was also analysed over different drives and days. For driving speed, 7 different locations on the virtual road were selected
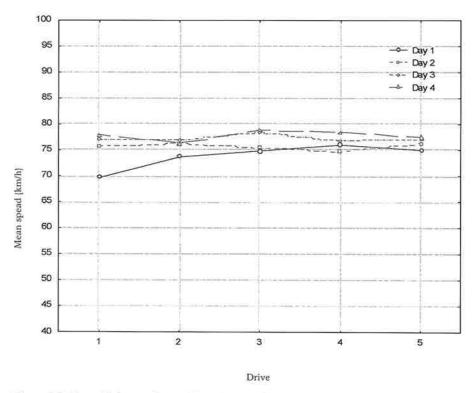

Figure 9.7 Mean driving speed over all locations as a function of Day (4) and Drive number within each day (5).

beforehand. These locations were interesting for assessing effects of familiarity and responses to changes, e.g. just before and just after the intersection that changed, just before and just after the intersection that did not change, and at a control location outside the built up area. The 7 locations are listed in Appendix 9.3. An increase in driving speed was found over days [$F(3, 33) = 10.30$, $p < 0.01$] and over drives [$F(4, 44) = 3.94$, $p < 0.01$]. The interaction between Day and Drive [$F(12,132) = 3.50$, $p < 0.01$] showed the largest increase per drive for Day 1 (see Figure 9.7).

Effect of change in priority situation

To assess the effect of the change in priority situation in driving speed, two types of analysis were performed. First, the mean driving speeds between the first drive of the second control condition and the last drive of the experimental condition were compared. The road layout for these two drives is exactly the same, but for the experimental condition, the last intersection was different (no priority) than all prior
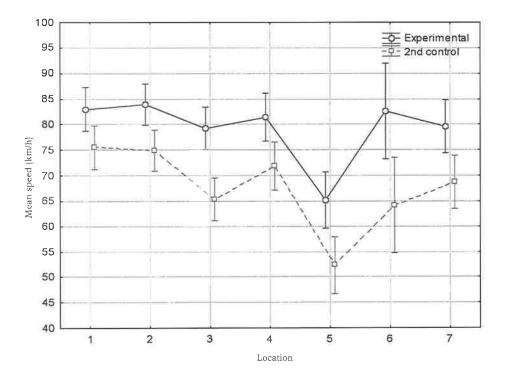

Figure 9.8 Mean driving speed on the 7 locations for drive 1 of the second control condition and drive 24 of the experimental condition. Note that participants of both groups encountered the same road environment, but on location 6, the experimental condition had encountered a priority intersection on the 23 prior drives. The bars indicate standard error.

drives (having priority). Since there was a general increase in driving speed over the drives in the experimental condition, it is not expected that the driving speeds between these two conditions are comparable per se. However, if the shape of the curve of driving speed on the 7 locations is similar for the two conditions with the exception of location 6, this may indicate that this difference is caused by the lack of perception of the changed situation (even though the intersections are the same, the participants do not respond the same). Also, a comparison of driving speeds on location 1 and 6 is made since here the traffic sign on location 1 indicates the same situation as was shown in the 23 prior drives on location 6. The data in Figure 9.8 show the driving speeds for the 7 locations.

What we can see is that in the second control condition, driving speeds for location 6 are lower than they are for location 1. This can be explained by the difference in priority situation (location 1 having priority and location 6 having to yield). This difference can not be found for the experimental condition (drive 24) with driving
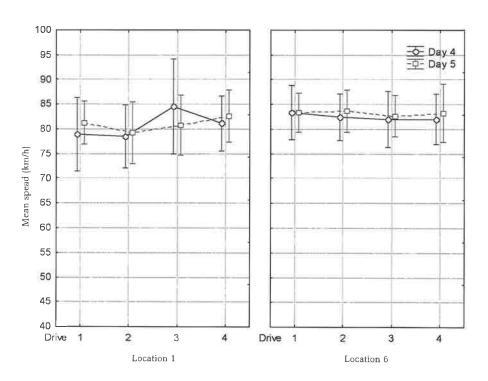

Figure 9.9 Mean driving speed on location 1 and location 6 as a function of day of testing and drive number within each day. Note that location 1 and 6 were the same, except for drive 4 on day 5. Here the intersection changed from having priority to having to yield. The bars indicate standard error.

speeds on location 6 being comparable to the driving speeds on location 1. The absence of a decrease in driving speed in the experimental condition is therefore interpreted as a lack of response to the change in priority situation.

Second, the driving speed over the last 2 days for location 1 was compared with that for location 6. If there is an increase in driving speed on location 1 that continues to be present in drive 4 on day 5, and this increase is absent for location 6 in drive 4 on day 5, this indicates that there was at least some response to the changed traffic situation (being the absence of an increase in driving speed). A Fisher LSD post-hoc test showed that for location 1, there was no significant difference in speed between drives 3 and 4 on day 5 ($p < 0.32$). This is also not the case for location 6 ($p < 0.45$), which is shown in Figure 9.9.

The absence of a difference in driving speed may again be interpreted as the absence of a response to the changed priority situation. Just after crossing the intersection, the experiment stopped and participants were asked if they noticed anything specific in this last drive. Ten out of the 12 participants claimed that they did not see anything remarkable. One participant said that she noticed something had changed when approaching the intersection (even though she could not specifically indicate what had changed). Another participant spontaneously reported a change when crossing the intersection at a high speed (therefore not showing an adequate response). He claimed that it was mean that we changed something since this was not previously indicated (apparently he had not seen the sign and just responded to crossing the road markings).

9.3.3 Traffic sign recognition test

In order to analyse whether participants actually had expectations in the different conditions, a traffic sign recognition test was performed. At the end of the experiment (at specific locations), participants had to select a traffic sign from a list of 20 traffic signs (see Appendix 9.1) of which they thought it had been present there during the previous drives (for the second control condition and the experimental condition) or that they considered likely there (for the first control condition that was exposed to the road for the first time). While participants slowly drove the road, the experimenter indicated these locations (identified by poles without a traffic sign) and participants had to select the traffic sign they considered to be the correct one at that specific location. The number of errors on the traffic sign recognition test was compared between the three conditions (the experimental condition and the two control conditions). The experimental condition had completed 24 drives in the same environment (with in the last drive a different traffic sign at the last intersection), while the first control condition had not been exposed to the road before and the second control condition only once. The number of correct responses was compared

using a Kruskal-Wallis test. There was a significant difference between the three conditions [$\chi^2(2, 36) = 28.99$, p < 0.01] The experimental condition scored better (5% mistakes) than the second control condition (24% mistakes) and both conditions scored better than the first control condition (50% mistakes). This means that exposure or familiarity indeed increases the expectations that subjects have about the content of traffic signs at certain locations (including the one at the last intersection). After 1 drive, participants scored better than guessing, but the expectations are even higher after being exposed to the same road numerous times. When focusing on traffic sign 10 (the sign that changed for the experimental condition in the last drive on day 5), we see that for the experimental condition, 11 out of 12 participants said that the ⚠ sign was shown there, whereas on the second control condition, 11 out of 12 participants said that the ▽ sign was shown. This suggests that expectations were controlling participants' perception.

9.4 Discussion

The present results are clear: When people drive a road, they develop expectations regarding the traffic signs. The traffic sign recognition test resulted in better performance for those who drove the road several times compared to people who drove the road only once. However, when having to report the last traffic sign that was changed in the last drive, people report the traffic sign that had been present there on previous drives, and not the one that had actually been presented to them in the last drive.

In addition the results show that the more often people drive a specific road the less time they spend glancing at traffic signs. This is in line with the results of Martens and Fox (2007) who found that under real driving conditions, drivers glance duration for objects along the road decreases if they drive a road numerous times. This effect is strongest on the first day. Apparently familiarity with the road increases rapidly on the first day and only slightly more on successive days. Presumably, the driver workload also decreases with increasing familiarity with the road, with drivers spending less time attending information they already know. This leaves more time for attending other items. Furthermore the expectations people developed during the course of the experiment were reflected the increase in average speed on various locations.

Finally our prediction that people that encounter one type of traffic situation several times will respond less adequately to a changed situation than participants that encounter this situation for the first time could not be rejected. Driving speeds for the yield situation were lower (and therefore more adequate) for people who drove the road for the first time compared to people who had driven the road several

times. Only 2 out of the 12 participants showed any response to the change, but only after crossing the priority road markings (shark teeth, see Figure 9.2) and not as a response to the changed traffic sign or in anticipation to the shark teeth. Glances at the changed traffic sign were as short as the glances at unchanged information suggesting that even though road users glanced at the sign they did not process it sufficiently to respond to it appropriately.

These results support the idea that with stronger expectations, less active information processing takes place (glance duration decreases, even if things change). When unexpected changes are introduced, the new information is not sufficiently processed thereby resulting in less adequate or even absent responses. Although participants did glance at the changed traffic sign (as they did with all other traffic signs that were familiar) they did not respond to it accordingly. In this case, driver perception seems to be the direct result of driver expectation with corresponding behaviour.

9.5 General discussion and practical implications

When reading the literature, one could assume that the greater the significance of the information for the driver, the more or the longer the glances it will receive. Several studies show that objects of central significance are fixated more than incidental objects and that hazardous objects are fixated more than the equivalent object in a non-hazardous situation (e.g. Hillstrom & Yantis, 1994; Loftus et al., 1987; Chapman & Underwood, 1998; Underwood, Chapman, Berger & Crundall, 2003). Underwood (1974) even states that with developing (driving) skill, it gets easier to divide attention without any impairment in processing the information relevant for the primary task (in this case driving). This is in correspondence with later findings (Underwood et al., 2003) that experienced drivers were better in recalling information about objects that were incidental to the main sequence of events without worse performance on task-relevant items. In case of our experiment, this would mean that participants would have more resources and time available for detecting new objects (such as the shartk teeth that were introduced) if participants have shorter glances at the familiar signs. Groff and Chaparro (2003) hypothesise that changes to task relevant items are detected faster than changes to non-relevant items and that the ability to detect changes should increase with the viewers task experience, but only to the extent that the type of change is meaningful to both the object and the task. They found that responses to driving task relevant items (a.o. traffic signs) were faster than to changes not relevant for the driving task. Furthermore, more driving experience led to a better detection of changes to traffic signs. Groff and Chaparro (2003) state that individuals use a schema along with their own experience to guide the allocation of attention to both the objects and features they consider most relevant to the task. They specifically state that individuals learn through repeated encounters which

information is most important and allocate their attention accordingly. Based on prior experience with a given task, an individual may employ specific search strategies in the absence of bottum-up saliency features to guide attention. However, again this does not explain the drawback of the system, referring to the current results of not adequately responding (or maybe not even noticing) changes.

Crundall, Chapman, Phelps and Underwood (2003) measured eye scanning patterns while watching driving videos with more and less experienced drivers. They found that with more experience, the fixation durations to items were shorter. This resulted in an increase in the sample rate, leaving more time to also fixate other locations. This increase in sample rate is assumed to illustrate a decrease in workload. Recarte and Nunes (2000) found that increasing workload resulted in less variability in the horizontal and vertical gaze positions, so in a reduced glance activity. Again, the literature mentioned here indicates that our participants would have had more time to detect the shark teeth.

The decrease in glance duration may be part of the problem. De Graef, Christiaens and d'Ydewalle (1990) and Henderson, Weeks and Hollingworth (1999) claim that the observer's eyes remain on each region until processing is completed. Glance duration under those conditions will depend both upon the complexity of stimulus features and upon the observer's task. However, in case of strong expectations, it may be that there is a top-down control over glance duration instead of bottom-up control. In that case it may be that glance duration reflects the processing time that the observers expects to need. Rensink, O'Regan and Clark (1997) claim that the allocation of visual attention is driven by a task-related schema, leading to the conclusion that more experience with a task should result in a more detailed schema and a more efficient allocation of attention. For our task this means that more experience with the road resulted in more efficient allocation of attention, illustrated by drivers taking shorter glances at objects they are already familiar with. However, Rensink et al. also state this would result in improved change-detection ability for objects more relevant to the task. In our experiment, the change in priority situation was not detected by the participants. Apparently the top-down control was far stronger than the bottom-up features from the presented information. Information that is highly relevant for the driving task is most likely not being perceived or at least not responded to if it does not fit the expectations.

There are some differences between the type of experiments cited and the current experiment. For example, in the Underwood et al. study, all hazardous situations had abrupt onsets as opposed to the current experiment with a gradual onset (the recognition of some object initially in the distance and as the participant gets nearer

it can be recognised as something that presents a danger). Also, in the Underwood et al. study, participants were told that they would need to answer questions, creating a specific mind-set probably with a more active visual information intake. This is definitely also the case for the Groff and Chaparro study, where subjects were even informed about upcoming changes, leading to active visual information processing. If people look but fail to sufficiently process changes in the traffic situation in case they are not warned for possible changes, this has serious consequences if adequate adaptation of behaviour to the changed situation remains to be absent.

Van Elslande and Faucher-Alberton (1997) refer to accident data that show that road users who are familiar with a site tend to perform their normal sequence of actions despite new or contradictory information. This clearly points to the strong top-down control, with little room for bottom-up features. The look-but-fail-to-see accidents (e.g. see Staughton & Storie, 1977; Herslund, 1993, 2001; Jørgensen & Jørgensen, 1994) are also assumed to be related to expectations. In look-but-fail-to-see accidents, drivers claim that they did not see the other vehicle until they were so close that a collision was unavoidable. In many cases, the driver looked in the appropriate direction (top-down control) but failed to give priority to the other vehicle, most likely since they did not expect any vehicle to be present (e.g. Rumar, 1990; Brown, 2005). Apparently, the presence of another road user did not have strong enough bottom-up features to actually result in a response. Brown (2005) even claims that these accidents are particularly likely when driving on very familiar roads, with drivers using stereotyped search patterns. Herslund and Jørgensen (2003) confirm that experienced drivers develop fixed routines for searching information.

The results of the current study have major implications for the real traffic environment where changes to local traffic situations can have a large safety impact if drivers do not notice this. In that sense, the effects in real life are expected to be at least as large for two reasons. One, the experimental set-up (where they know they are being watched) normally has participants pay attention to good performance, whereas this may not always be the case in real driving. Second, a simulated environment in an experimental set-up may be more likely to change than a real environment that never changed in the last 2 years that someone has driven that route.

The question that remains is what type of information would bring the driver to a state of active information processing, increasing the changes of appropriate responses? Would adding instead of just changing a road sign help? The next step in research would be to find out what type of information would be able to break though this passive information processing state. With timely warnings that something actually changed in the driving environment, an adequate action is likely to result.

Appendix 9.1

The traffic sign recognition test, using general Dutch signs (second sign in the first row indicates 'Yield', third sign in the third row means 'End forbidden to overtake').

Appendix 9.2

Traffic signs as used in the analyses of the experiment.

Traffic sign 1: Priority crossing

Traffic sign 2: Loose gravel

Traffic sign 3: No overtaking

Traffic sign 4: Curve to the left

Traffic sign 5: Curve to the right

Traffic sign 6: Curve to the right

Traffic sign 7: Maximum speed limit

Traffic sign 8: Children

Traffic sign 9: End speed limit

Traffic sign 10: Priority Crossing

Appendix 9.3

The selected road locations for analysing speed

1) 200 meters before the first intersection
2) 200 meters after the first intersection
3) 200 meters on a control location
4) 200 meters before the start of the urban area
5) 200 meters after the start of the urban area
6) 200 meters before the last intersection
7) 200 meters after the last intersection

10

Does road familiarity change glances? A comparison between watching a video and real driving[4]

10.1 Introduction

When a road user drives along a road, different aspects of the environment demand and compete for attention. How does this process of allocating attention to different objects work and how do drivers select information? It is expected that attentional factors such as motivation, expectation, vigilance, mental effort and divided attention play a crucial role in visual selection performance. Hughes and Cole (1988) state that the driver's information needs should have a significant effect on visual search strategy. When people are uncertain about their surrounding environment, for instance if they are driving in a new road environment, they will be more actively searching for information. Theeuwes (1989) states that top-down visual search only takes place when a driver is uncertain about the situation, and is actively searching for information in order to reduce this uncertainty. This implies that in a road environment that is highly predictable to the driver (for instance because he or she has driven the road numerous times), the driver may not actively search for relevant objects and may pay less attention to the driving task.

Martens and Fox (in press) addressed this issue in a simulated driving task. They showed that drivers spent less time glancing at traffic signs the more often they drove a particular road stretch. In addition, even though these drivers glanced at the traffic signs less often they knew what was displayed on these traffic signs, suggesting that driving the same road several times leads to stronger explicit expectations. One could argue that it is only logical that items that have been encountered before are glanced at for shorter periods of time. Studies have shown that viewers tend to cluster their fixations within informative regions of a scene (Antes, 1974; Buswell, 1935; Mackworth & Morandi, 1967; Yarbus, 1967). If one already knows what certain objects respresent (because it was fixated before), it may be semantically less interesting. However, other studies found that viewers were no more likely to fixate the more informative target object than the less informative object early during scene viewing (Henderson, Weeks & Hollingworth, 1999; De Graef, Christiaens & d'Ydewalle, 1990), and Friedman (1979) found no effect of informativeness on the number of discrete looks to an object from a position beyond that object. This definition of 'informativeness' remains to be the problem in many studies, showing the relationship between informative scene regions and fixations (Mackworth & Morandi, 1967; Antes, 1974; Buswell, 1935; Yarbus, 1967). In reading, it has been found that unfamiliar words require longer fixations than common words (Rayner & Pollatsek, 1989). The idea here is that unfamiliar words (as may be the case for unfamiliar objects) require more processing and therefore the measure of fixation duration may be considered to reflect object identification time (Henderson, Pollatsek & Rayner, 1987; Underwood & Everatt, 1992). However, the direct transfer from this knowledge of reading or watching pictures to looking while driving a car or watching a video of the driving scene remains to be difficult.

Given the findings of Martens and Fox (in press), one can argue that people only need to passively update their existing mental model if they are familiar with the environment, which appears to require less attention than actively encoding the environment. These results are in correspondence with findings of Martens (2004). She found that in artificial experimental settings, participants spend more time glancing at objects they consider to be relevant (targets among distractors). In this sense, a traffic sign can be considered to be less relevant if the information on the sign is already known.

However, a problem with the notion of passively updating the mental model is that it may very well be that drivers do not notice changes to road environments if they are not actively scanning their surroundings. First studies in simulated task environments have shown that quite a large part of the participants do not notice information that is not in accordance with their expectations or when they do notice, their responses are delayed (Martens, 2004; Martens & Fox, in press). This negative side of getting familiar with a certain task environment might be the result of not spending enough time glancing at the objects in the task environment. But this decrease in glance duration to objects in the task environment once people get familiar with the environment has only been shown in computer simulated environments. It would be important to determine whether passively scanning the objects in the surrounding once people get familiar with the environment can also be found in the real world.

Many studies have shown that attention and eye movements are guided by a common selection process (Bichot, 2001). We attend to objects of interest while ignoring irrelevant ones. Mori and Abdel-Halim (1981) found that under free driving conditions (without a specific search instruction) only 11.2% of the traffic signs were fixated for a duration that was equally long compared to the condition in which participants were instructed to read all the signs. Zwahlen (1981, 1987, 1988) reported that driver's eye scanning behaviour is not much different for warning signs, advisory speed signs, curve signs, stop ahead, or stop signs although these signs have different guidance or warning purposes. For stop signs, Zwahlen (1988) found that test drivers fixated the signs on average between 1.45 and 2.77 times, with an average duration of between 650 and 820 ms. Curve warning signs were fixated on average between 1.6 and 3.5 times, with an average fixation duration of 510 to 620 ms (Zwahlen, 1987). Luoma (1988) studied the interdependence between fixations of the eyes and conscious perceptions during driving. This study addressed the controversy whether looking at an object actually entails "perceiving" (remembering) that object. He found that traffic signs that appeared in isolation were almost always perceived foveally and signs that were fixated were also always perceived. Road advertisements were perceived rather seldom, although one could argue that they may have been perceived and forgotten immediately since they were not traffic

related. The glance duration for the traffic signs was between 410 and 644 ms on average. Luoma states that a relatively short glance may be an indication of adequate characteristics of traffic signs related to information ergonomics. On the other hand too short a glance did not lead to perception (127 ms for a pedestrian crossing sign and 283 ms for a pedestrian crossing ahead sign). This last result is again a reason to believe that too short glances at specific objects because drivers are familiar with the road does not lead to perception and therefore changing information on a sign to indicate a changed situation may lead to dramatic results if this change in information is not perceived.

The objective of the present study is to show that this observed decrease in glance duration over subsequent drives, wich may result in worse performance when things in the environment change, is also found under real driving conditions. In line with the previous findings it is expected that the more often a driver encounters a specific road, the less time he/she will spend glancing at specific objects, such as traffic signs. Glance durations could be different in a real driving task since the simulated and lab tasks that Martens (Martens, 2004; Martens & Fox, in press) used were less varied than real driving conditions, not having all elements that occur in a real traffic environment. First, typically in real driving there are many more visual elements along a road (houses, trees, pedestrians, cyclists, other cars) than there were in the simulated tasks. Second in real driving there is more variation from one trial to the next (difference in opposing traffic, different weather conditions, different pedestrians etc.). Third, typically the drivers' field of view is wider in real life than in a lab environment with a computer monitor. It might therefore be the case that the decrease in glance duration found in the simulated environment is primarily due to the absence of any change from run to run, and not per se applicable to real driving scenarios. Fourth, the luminance values of simulated traffic signs on a computer screen do not correspond to the luminance values of signs in the real world, and the resolution of the image projector in simulations is somewhat limited. This results in recognition distances in a simulated environment that are smaller than in practice (Godthelp, 1980; Alferdinck & Hoedemaeker, 2004). This limited resolution may also result in differences in behaviour between real driving and simulated driving, as were found in a study with participants approaching a still-standing vehicle at high speeds and braking at the last moment possible. Only at high speeds, participants used a higher safety margin in the simulator compared to real driving (Kaptein, van der Horst & Hoekstra, 1996). In the range of more high-end simulators, these differences will be less.

In addition to the goal of replicating previous findings concerning total glance duration in a real driving task, the study assesses whether there are differences in glance durations for specific objects between driving a particular road stretch

and watching this very same road stretch on video. The main difference between driving and watching a particular road stretch is that actual driving is more risky (things may happen that are not under control of the experimenter and situations may be different between various participants). By comparing the glance durations found in real driving with glance durations when watching a video (and pretending to be driving), it can be determined whether using videos as stimulus material for assessing glance durations and decreases in glance durations to specific objects would be feasible for future studies. In the current experiment, it was deliberately chosen to actively involve the viewers of the video by having them pretend to be driving. If participants watch a video of the same road several times for several days, it may be that boredom leads to daydreaming (probably to a less active eye scanning patterns than people would have in real driving) or to attention being drawn to other objects not relevant to the driving task. Although this is an interesting research question in itself, the main goal of this experiment was to find evidence that assessing total glance duration and frequencies when participants get familiar with a certain type of road environment can be done with showing videos as well as in real driving conditions. Since there was some doubt whether this would succeed in the condition of passively watching a video (due to the familiarity aspect), it was decided to have participants simulate they were driving. If this turns out to be a valuable tool for assessing glance durations to specific objects, this will suggest that time-consuming field experiments (you have to drive to a specific area) are not really necessary anymore. In addition, it allows experimental control over adverse effects of weather conditions (bright sunshine is not to be preferred in eye movement studies) and variance between different conditions to which participants are exposed (it is hard to make sure that all participants receive the same situations). An advantage of showing a video while participants simulate to be driving compared to just showing a video is that responses to certain situations can also be measured, such as letting go of the gas pedal (or braking) before entering a curve or a braking response to an unexpected event (braking lead vehicle, child crossing the street etc.). It also offers the possibility to change things in the same road environment from one drive (video scene) to the other (something which is almost impossible in real life) but still show a very realistic image (compared to some simulations in which specific colours may be far more conspicuous than they would be in real life). This offers some more flexibility in the types of issues to be investigated compared to passively watching a video. The driving behaviour itself is however not part of this study.

There are a few studies that compared driving in real traffic with watching the very same road on video passively. However, these studies were not focusing on glance duration, but rather on performance or obstacle conspicuity. Hughes and Cole (1986) instructed drivers to verbally report all the objects that attracted their attention. Half of the participants watched a 16mm colour movie made from the route and half of

the participants actually drove a vehicle in this environment. The verbally reported data indicated that in comparison to real driving a movie provided a reasonably adequate simulation. The problem with the study is that verbal reports may omit information that participants use to perform a task (Ericsson & Simon, 1980). There is even some evidence that in verbal reports, participants do not report all items they actually perceive, since the percentages for reported traffic-related items are quite low in several studies (a.o. Hughes & Cole, 1986; Renge, 1980). It might very well be that participants see more than they can verbalise, since verbalising takes more time than perceiving per se (Martens, 2000). MacDonald and Hoffman (1984) found that retrospective verbal reporting of road sign information in a laboratory experiment using movie satisfactorily replicated results obtained in a field trial. These studies suggest that the absence of the driving task did not have a substantial effect on reporting behaviour. Again, in these studies, glance durations to specific objects were not measured, so it remains unclear whether this comparison of results also holds for glance durations. Hughes and Cole (1988) investigated eye movement behaviour involving participants watching a video without any other task and with a compensatory tracking task. The tracking task was located near the focus of expansion and was intended to be a simulation of the kind of demand imposed by longitudinal vehicle control. In the free conditions participants were just asked to watch the film, in the memory condition participants were told that they would need to answer questions about the film afterwards. In the attention conspicuity condition, participants had to report all objects that attracted their attention and in the search conspicuity condition, participants had to report all road traffic control devices and experimental disc targets along the route. Watching the video resulted in a broader distribution of horizontal fixation locations compared to the conditions in which participants were also performing a tracking task. The left region (Australian study, so road signs were located on the left side) was progressively more fixated as the specificity of the instruction changed from free observation to search. Under completely non-directed observations (free) the left region lost its apparent importance so that sky, road and central regions assumed just as much importance in attracting fixation. Hughes and Cole state that a driver does not passively acquire information but instead makes some attempt to purposefully interrogate the visual environment based on his information requirements and previous knowledge about the location of specific objects in the road scene. Cohen (1981) found that eye movement behaviour differed between drivers viewing the road and observers looking at a photograph of the same scene. However, this study was done under static conditions and may therefore not be applicable to the current research question. Lee and Triggs (1976) found that the detection of peripheral lights from a vehicle was not affected by whether the observer was a driver or a passenger, assuming that the act of driving

makes insufficient demand to affect visual behaviour. However, in Lee and Triggs' study, participants were under all conditions confronted with the 'real life' traffic scene, something which is not the case for a video experiment.

The current experiment was conducted to determine whether the decrease in glance duration, as found in simulated environments, often leading to inadequate responses to changes in the environment, is also found in real driving. Second, the experiment is conducted to determine whether having participants watch a video while simulating driving is a valuable tool for analysing glance duration and glance frequency to specific objects.

10.2 Method

10.2.1 Participants

A total of 28 paid participants took part in the experiment. Participants were randomly assigned to one of two experimental conditions; the field condition (real driving) or the video condition. The ages ranged from 21 to 46, with both male and female participants included. All participants considered themselves to be experienced car drivers (having their driver's license over 3 years and driving regularly). All 28 participants reported to have adequate visual acuity. None of the participants wore glasses or hard lenses, because of possible interference with the eye movement measurements.

10.2.2 Apparatus

A pupil/cornea reflection eye tracking system (ISCAN) was used to measure the eye movements of the participants. This was done by illuminating the left eye with an infrared source. A camera obtained a clear image of the eye by using an infrared pass filter to identify the dark image area of the pupil. Another camera mounted slightly below the left eye recorded the participant's field of view. If the system is adequately calibrated, the system has an accuracy of 1 degree of visual angle. The eye tracking system had to be calibrated to the participant's eye by means of five different calibration points. For every individual participant, the calibration procedure was performed before the start of the drives every day. The eye's pupil and corneal reflection positions were calculated with a sample frequency of 120 Hz. The camera that recorded the participant's field of view was connected with a Panasonic VCR. The camera image with the glances included was recorded on VHS tapes for later analysis. The cameras and the infrared source were built into a specially designed cap (see Figure 10.1). During the experiment, participants could move their heads like they would normally do while driving.

Figure 10.1 The ISCAN eye movement equipment that was used during the experiment with the apparatus being attached to a baseball cap.

In the video condition a video taped from the driver's point of view was played back on a Panasonic VCR and projected on a video screen by means of a HITATCHI XGA beamer. The projection screen had a width of 3 meters and a height of 2.5 meters. Participants were seated approximately 2.5 meters from the projection screen. A Logitech force feedback steering wheel and pedals (braking pedal and gas pedal, automatic gear) were used as input devices for the video condition. Participants were asked to pretend they were the driver of that car and to copy the steering, gas and braking behaviour of the 'virtual' driver. The virtual speed of the participant, measured by the force on the gas pedal, was shown on a separate display on the table in front of them. The simulated sound from the engine (linked to the virtual revolution-counter) was generated on a Pentium II computer and was played back using computer speakers attached to a Creative SoundBlaster soundcard.

The car used for taping the video condition was a Chrysler Voyager. For the field experiment (real driving condition), participants drove a Dodge Ram Van with an automatic gear. Just like every drive for participants in the field condition would

vary, the videos were also recorded over different drives, which led to differences between every video, but not to differences between participants (whereas there was a difference from participant to participant in what they encountered in the real driving condition). In the field experiment, the driving speed between participants could vary (since they regulated their own speed) whereas this was not the case for the video condition.

10.2.3 Task

The route (in both the field condition and the video condition) took the participants along a two lane road that was partly a rural road and partly an urban area. The total length of the route was 18 kilometers. Participants in the field condition were required to drive from the starting point to an end point, make a U-turn and drive back to the starting point. This was done four times in a row on one day with an instructor in the car providing directional information. Participants were instructed to drive as they would in normal life and drove with an automatic gear. The video condition showed the same route from a driver's point of view, with the route projected on a video screen. The videos only showed the route itself, so the U-turns were not included in the video. To make sure there was enough variety in the video condition from one day to the other (as there would be for the field condition), video recordings of the route were made on three different days. To make the task more realistic, participants were instructed to copy the behaviour (steering, braking, and gas) of the 'virtual' driver from the video as good as possible. They were told that their actions would be recorded and that their driving behaviour would be compared with that of the virtual driver as a performance indicator. This was done to keep the participants' attention committed to the driving task.

10.2.4 Conditions

The experiment consisted of two conditions; the field condition in which participants drove the 18 km route in a car and the video condition in which participants watched the same route from the viewpoint of a driver.

10.2.5 Procedure

In both conditions participants began with reading instructions before the actual experiment began. Participants were also verbally instructed to drive as if this was their daily trip home from work and to obey the traffic rules as they normally would. After reading the instruction, the baseball cap with the eye movement equipment was put on their head, participants were seated behind the steering wheel and the eye movement apparatus was calibrated by means of 5 different calibration points. The participants were told not to touch the cap containing the eye movement apparatus after the calibration process.

In the video condition participants sat behind the steering wheel and had a clear view on the video screen. When the video started participants were asked to 'begin driving' and 'keep driving' until the video stopped. Just like in the field condition, the participants 'drove' the route four times on one day without a break. Before every drive, a number on the video screen would indicate the drive number for participants to understand they would now start a new drive. The experimenter left the participant alone in the video room and went to an adjacent room with a window allowing a view on the participant. The only information provided by the driving instructor was the direction.

In order to build up expectations, participants either watched the video or drove the route four times in a row on three successive days. The video sequence was presented to all participants in the same order. It was decided to use three days since Martens and Fox (2003) found that the decrease in glance durations over days stopped more or less after three days.

10.2.6 Statistical analysis

The dependent variables used in this experiment were the total glance durations of specific predefined targets and the total number of glances (glance frequency) to the predefined targets. These two measures have been used before (a.o. Zwahlen, Russ & Schnell, 2002; Zwahlen, 1995) for assessing the information acquisition processing of road signs during normal driving.

A power analysis was performed for both dependent measures. In case that statistics did not show any effect, the power analysis was consulted in order to check if the data had sufficient power to reveal potential effects. If this was not the case, this will be stated when describing the absence of any effect. The probability of a Type I error was maintained at 0.05 for all subsequent analyses. In order to compare the total glance durations and glance frequencies, analyses of variance were performed with the independent variables Condition (with 2 levels, field or video), Day (with 3 levels), Drive (with 4 levels) and Object (19 different objects). Altogether 19 objects were selected out of a total of 42 signs the participants encountered along the route. The objects were selected to come to a combination of varied objects (road signs, markings on the road, informative signs, signs with symbols and signs with text, etc). Some objects were presented more than once. This allowed us to look at the differences between these signs. The 19 different objects are described in Appendix 10.1. If there is a number between brackets, this means that this object was not stand-alone but was combined with other objects in lateral position (e.g. (2) means that this object was combined with one other sign).

We use the term total glance duration for the summation of the total time participants glanced at the object. A cross superimposed on the road scene indicated the actual glance direction. All drives with the glance direction superimposed were taped on video. The analysis of these data was done by slow-playing the video with a reduction factor of 5 (5 times slower than normal playing speed). Every time the cross (glance direction) was within a range of 0.5 cm around a traffic sign within the area between 250 and 0 meter in front of the traffic sign (at this distance the traffic signs were clearly visible) this was recorded to be glanced at. If a participant glanced outside this spatial window the next glance inside this spatial window was considered to be a new glance. Although the acquisition of glances was done manually, the criterion of 0.5 cm was marked on the screen and did therefore not leave room for any subjective interpretation. The relevant objects never obscured one another (which could have led to confusion which sign was glanced at). Since it was a dynamic scene, participants followed the object with their eyes as it 'moved' relative to the participant, which also facilitated the decision what object was being glanced at.

10.3 Results

10.3.1 Comparison glance durations and frequencies between video and real driving

In order to determine whether there was a difference in total glance duration to the pre-specified objects between the two conditions, glance durations between real driving and watching the video were compared. There was no significant main effect of Condition on glance durations.

For glance frequency, there was a difference between the two conditions [$F(1,26)$ = 6.43; $p < 0.02$] with some more glances at the objects in the video condition (average of 0.91 glances over all objects in the video condition and 1.04 glances in real driving).

10.3.2 Familiarity with the road environment

For total glance duration, there was a main effect for Day [$F(2,52)$ = 47.23; $p < 0.0001$], with a decrease in glance duration over days. This was also the case for glance frequency [$F(2,52)$ = 11.80; $p < 0.0001$]. Also a main effect was present of Drive on total glance duration [$F(3,78)$ = 6.76; $p < 0.0004$] with decreasing glance duration with an increasing number of drives. The effect of Drive on glance frequency [$F(2,52)$ = 3.33; $p < 0.02$] showed the same type of pattern. In general it can be claimed that the more often people encounter the same road environment, the less time they spend glancing at objects, by decreasing the number of glances and by decreasing the glance duration per glance. For total glance duration, there was an interaction between Day and Drive [$F(6,156)$ = 2.31; $p < 0.037$].
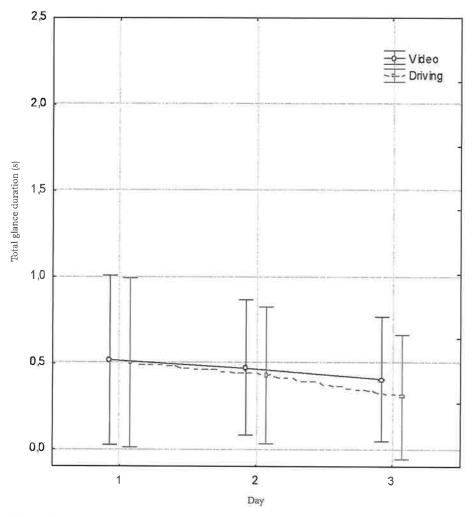
Figure 10.2 The 2-way interaction between **Condition** and Day on total glance duration (s). The error bars indicate the standard error.

The decrease in glance duration was mainly present for the 'priority road' sign, the 'warning horse back riders' sign, the 'curve to the right' sign, one of the 'speed limit 50' signs, the 'start urban area Soest' sign and the speed camera. The decrease was absent in case of the 'warning pedestrians' signs, two of the other 'speed limit 50' signs and the 'end speed limit 50' sign.

In case of the normal driving task under real driving conditions, traffic signs were not selected by road users in about 20% of the cases during the first drive. After driving the same road several times, traffic signs were not selected in about 25 to 35% of all
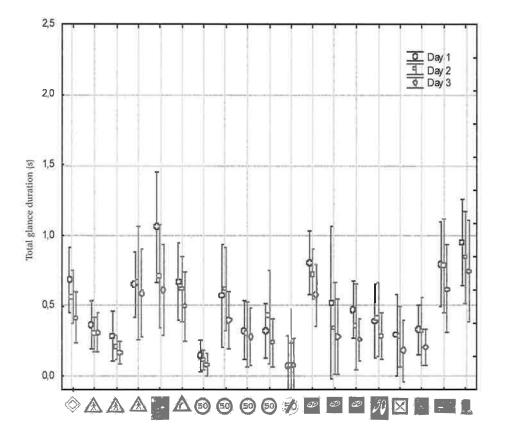
Figure 10.3 The 2-way interaction between Day and Object on total glance duration (s). The error bars indicate the standard error.

cases. When this same road was presented on video, this percentage was about 45% of the cases for the first drive. After virtually driving the same road several times in video, this was between 40 and 50% of all cases.

10.3.3 Type of object

There was a main effect of Object for the total glance duration [$F_{(18,468)}$ = 25.19; $p < 0.0001$] and for glance frequency [$F_{(18,468)}$ = 30.26; $p < 0.0001$], with quite large differences per object. The type of effect was similar for total glance duration and glance frequency.

A post-hoc Comparison (Fisher Least Significant Difference (LSD)) showed which objects differed from one another. It was important to determine which objects
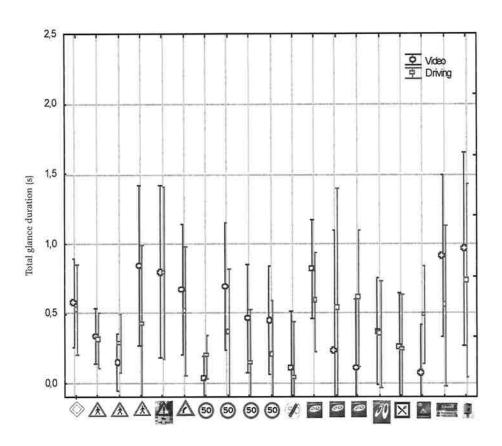
Figure 10.4 The 2-way interaction between Condition and Object on total glance duration (s). The error bars indicate the standard error.

received long glances and which objects received short glances. Some precaution is needed when explaining long or short glances purely to the objects themselves. There may always be an effect of other factors such as background or objects in the vicinity, something that was not specifically controlled for here. The most important conclusion is that over all drives and days and conditions, the objects that received the longest total glance durations were the 'warning horse back riders', 'start urban area Soest' and the speed camera. The 'warning horse back riders' sign also received the largest number of glances.

The shortest glances were found for 'speed limit 50' (object 7) and 'end speed limit 50' (object 11). These signs also received the lowest number of glances.
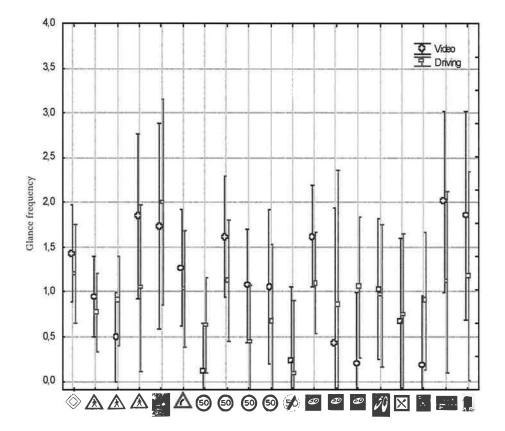
Figure 10.5 The 2-way interaction between Condition and Object on glance frequency. The error bars indicate the standard error.

For total glance duration, there was an interaction between Object and Day [$F(36,936)$ = 1.61; $p < 0.014$], with the decrease over days being larger for some objects compared to the other. This effect is shown in Figure 10.3.

A post-hoc comparison (Fisher LSD) showed that even though glance duration decreases over days, the objects that received the longest glances on day 1 are also the objects that received the longest glances on day 2 and day 3. This is also the case for objects having the shortest glances. However, the group of objects that received the longest glances increased with the days, since the total glance duration over days decreased (the high peaks for some objects decreased). This was also the case for the shortest glance durations; all objects that received the shortest glances on day 1 also received the shortest glances on day 2 and 3.

There is a 2-way interaction between Object and Condition for the total glance duration $[F(18,468) = 8.23; p < 0.001]$, with the total glance duration differing per condition. This interaction is shown in Figure 10.4 for the total glance duration.

A Fisher LSD showed a difference for two 'speed limit 50' signs (object 8 and 9, $p < 0.01$ and $p < 0.02$ respectively, with longer glances for video), two 'painted speed limit 50' signs (object 13 and 14, $p < 0.02$ and $p < 0.0003$ respectively, with shorter glances for video), 'warning speed camera' (object 17, $p < 0.002$, shorter glances for video), ' start urban area Soest' (object 18, $p < 0.006$, longer glances for video), and 'warning pedestrians' (object 4, $p < 0.002$, longer glances for video). The 2-way interaction between Object and Condition was also present for glance frequency $[F(18,468) = 9.68; p < 0.0001]$ and is shown in Figure 10.5.

There was a 3-way interaction between Day, Drive and Object, both for total glance duration $[F(108, 2808) = 1.51; p < 0.001]$ and for glance frequency $[F(108, 2808) = 1.31; p < 0.02]$. Also, a 4-way interaction between Condition, Day, Drive and Object was found for total glance duration $[F(108, 2808) = 1.36, p < 0.009]$ and for glance frequency $[F(108, 2808) = 1.29; p < 0.03]$.

10.3.4 Comparison on the first drive

This study was mainly conducted to investigate whether the decrease in total glance duration to road signs with increased exposure to the same environment in a simulated environment was also present in real driving and in watching a video while simulating driving. However, from a methodological viewpoint it would be interesting to see if there are any differences between these two conditions in the first drive on the first day. It may very well be that if familiarity would not have played a role, looking into the data from just one drive (not being interested in a possible change in glance durations after numerous exposures), results are different. When analysing the total glance duration data of the first drive that participants made, there was no main effect for Condition. There was a main effect of Object $[F(18,468) = 9.57; p < 0.0001]$ and an interaction between Condition and Object $[F(18,469) = 3.64; p < 0.0001]$. This interaction is shown in Figure 10.6.

Selecting the objects that received the longest glances in the video condition did not lead to the same results compared to selecting the objects that received the longest glances in the real driving condition. Although there was overlap (some objects scored longest glances in the video condition and in the real driving condition), this was not the exact same selection of objects. There were quite large individual differences.
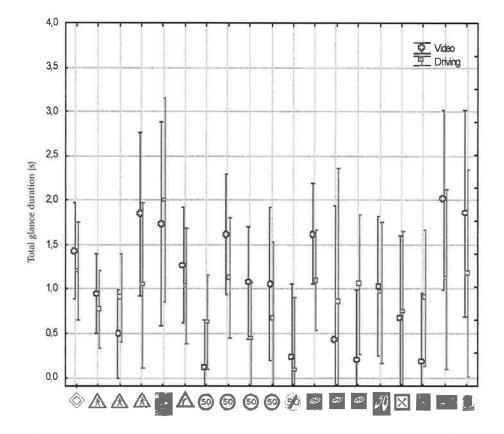
Figure 10.6 The 2-way interaction between Condition and Object on total glance duration (s) for the first drive on the first day. The error bars indicate the standard error.

For glance frequency, also no effect of Condition was found, an effect of Object $[F(18,468) = 12.20; p < 0.0001]$ and an interaction between Condition and Object $[F(18,468) = 3.55; p < 0.0001]$, basically showing similar results as total glance duration. The interaction between Condition and Object indicates that the effect of type of object on the total glance duration and glance frequency differs between the two conditions.

10.4 Discussion and conclusions

The results show that using the total glance duration and glance frequency in a video condition with simulated driving instead of during real driving needs some caution. When looking into the decrease of total glance duration over days, as was

found before in simulated task environments, this phenomenon was present for the real driving condition as well as for the video condition. However for day 3, the total glance durations for the video condition are a little longer than for the real driving condition (see Figure 10.2). This may be explained by the fact that in the video condition, there are limits to the resolution of the projection. Due to the limitations in resolution of the projection, a 'floor' effect could have caused this small effect. It could have been the case that the lowest possible identification times for the video condition may be higher than the lowest possible identification times for the real driving condition. Therefore, it may be harder to get an equal reduction in glance duration after a certain point (floor) due to the difficulty to identify the objects at an early stage. However, there might be other explanations; participants in the real driving condition may encode the glanced objects more deeply and thus may become familiar with them more quickly. Alternatively, participants in the real driving condition may have diverted their attention quickly from the objects of interest in order to deal with other more pressing demands in the real-world driving task. No interaction was found for glance frequency, indicating the pattern for day was the same for both conditions. However, this conclusion does not necessarily hold since the power of this effect was low. The decrease of total glance duration over days and drives was more the result of people glancing at an object shorter per glance and less glances than the mere result of people having a lower number of glances at the different objects over days and drives. Irrespective of the explanation, the results indicate that the decrease in glance durations for objects after numerous exposures to the same road is present in both the field condition and the video condition. However, caution is required when using the exact values of the decrease in glance durations after numerous days. Also, the number of glances at objects is generally a little higher for the video condition, probably explained by the fact that under real driving conditions participants have more objects to glance at (wider viewing angle) and the driving task may be more pressing than with simulated driving.

There is also a clear difference in total glance duration between the individual objects, with some objects receiving longer glances than others, with quite some individual differences. Most of the objects that received the longest total glance duration also received the largest number of glances and this also held for the shortest glance durations and the least number of glances. However, an interesting element is that in general the decrease of total glance duration over days was present for all objects, and that objects that received longest glances (compared to other objects) at day 1 still received longest glances (compared to other objects) on day 2 and even on day 3. This may lead to the conclusion that objects that do attract longer glances (relative to other objects and irrespective of the number of glances) remain to do so even after

people have seen or have driven this road numerous times (even though the absolute total glance duration decreased). However, an object that receives long glance durations on one location does not necessarily do so on another location. Based on these results, it seems impossible to claim that certain signs always receive short (or rather long) glances. Also, the claim that glance durations to objects presented in combination with other objects suffer in comparison to objects presented alone does not hold. Differences in glance durations between similar objects cannot simply be explained. The results for glance frequency were not directly related to total glance duration, not leading to the same stable decrease with exposure.

When comparing the glance data of the objects for the first drive of the first day, there was no systematic difference between the video and the real driving condition. However, the interaction between condition and object shows that total glance durations and glance frequency to the individual objects differ between the two conditions. Using the total glance duration or glance frequency data to select the objects in the video condition that received the longest glance durations does not lead to the exact same results as are found in the real driving condition, although there is overlap in identified objects in those categories.

Over all objects, no difference could be identified in the interaction between day and drive between the two conditions, neither for the total glance durations nor for glance frequency. However, the interpretation of this result should be dealt with care, since power of this specific effect was low. Over all drives, there was no difference in the interaction between day and object between the two conditions (again neither for total glance duration nor for glance frequency) and over all days, there was no difference in the interaction between drive and object for either parameters.

The present study confirms in part of our previous simulator study (Martens & Fox, in press) showing that drivers spend less time glancing at specific objects the more they drive a specific road stretch, but this time the results were found in a real driving situation. Also in the video condition this decrease was found. The results are also in line with earlier studies showing a decrease in total glance durations after numerous exposures to the same task environment in non-driving situations (Martens, 2004). This suggests that the decrease in glance durations as found before in the simulated environment, leading to drivers only passively updating their mental model and leading to a higher chance of missing changed information is also present in real driving. This illustrates a possibly serious safety risk.

10.5 General discussion and practical implications

In general it can be stated that the use of video (with instructions to participants that they have to simulate they are driving) for analysing total glance duration and glance frequencies for road signs can indeed be feasible for a limited selection of purposes, but that great care is needed. One of the main outcomes of the current study is that the decrease of total glance duration with increased exposure that has been found in simulated environments was also found in real driving. A second important outcome is that this decrease has also been found in the video condition. This means that over all objects, the two methods lead to comparable results when investigating total glance duration to objects. For glance frequency, people have slightly more glances at an object when watching a video compared to real driving and the decrease with increased exposure is not as gradual as it is with total glance duration.

However, when making a distinction between different objects, e.g. when looking into the objects that received the longest or shortest glance durations, there are indeed some differences between the two conditions. This means that the video configuration is not useful for identifying objects that would receive longest and shortest glance durations under real driving conditions. Although there are objects that receive the longest glances in the video condition that also receive the longest glances in the real driving condition, there is no exclusive overlap. So despite the fact that some studies have found similar results when comparing verbal reports during driving with watching a video (MacDonald & Hoffman, 1984; Hughes & Cole, 1986), this does not simply correspond to total glance durations to objects along the road.

This study did not look into the difference in glance duration and glance frequency between watching a video and watching a video while participants pretend to be driving. The results from the current experiment show that the latter method should only be used for exploratory or pilot research, looking into glance durations to road objects. The video tool is suitable for looking into the effect of multiple exposures or familiarity with the road environment on total eye glance duration without being interested in exact glance durations to objects as they would be in real life.

Appendix 10.1

List of 19 objects.

|		
1)	Priority road	
2)	Pedestrians	
3)	Pedestrians (3)	
4)	Pedestrians (2)	
5)	Danger horseback riders (on supplemental sign)	
6)	Curve to the right (2)	
7)	Speed limit (3)	
8)	Speed limit	
9)	Speed limit (2)	
10)	Speed limit (2)	
11)	End speed limit	
12)	Speed limit (50) painted on road (3)	
13)	Speed limit (50) painted on road	
14)	Speed limit (50) painted on road (2)	
15)	Speed limit (50) painted on road (2)	
16)	Information sign restaurant	
17)	Warning sign speed camera	
18)	Start urban area "SOEST" (2)	
19)	Speed camera	

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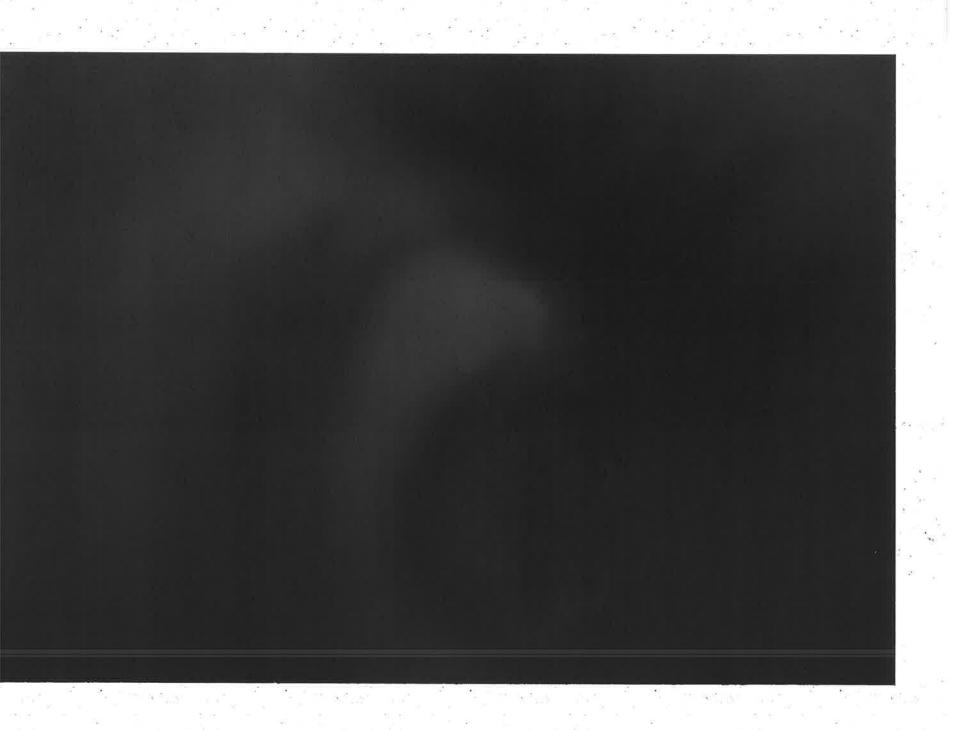
11

'The failure to apprehend'
in case of changes to the road environment:
does familiarity make a difference?

11.1 Introduction

Traffic accidents are caused by many different factors. One of these factors is driver distraction. In many cases, driver distraction refers to distraction by something inside the vehicle. Examples are a driver who looks at an in-vehicle display or changes the radio station. When a driver takes his eyes off the road and looks inside the vehicle, it seems plausible that he can not respond to what happens outside on the road. The information on the road never enters the visual system, leading to a failure to respond. However, an interesting but dangerous phenomenon arises when drivers are looking at the road but still fail to select or respond to information relevant for the driving task. We refer to this phenomenon as 'the failure to apprehend'; the information is clearly visible and relevant for the task at hand, but there is no response.

Examples of this phenomenon are described in Danish studies, that specifically look into traffic accidents at priority intersections (Herslund, 1993, 2001; Summala et al., 1996; Räsänen & Summala, 1998; Rumar, 1990). They describe accidents in which drivers, after hitting a cyclist who had priority, claim that they did not see the cyclist even though they specifically looked for other traffic. These types of accidents are so called looked-but-failed-to-see accidents (Hills, 1980). Although not scientifically proven, one of the explanations is that drivers only look for other cars. They do not detect cyclists or motor cyclists since they do not expect other road users but cars to be present.

In this respect, top-down visual search plays an important role. Top-down visual selection takes place when people select objects from a scene that share some features with the specific target object they are looking for (e.g. Treisman & Gelade, 1980; Wolfe et al., 1989; Findlay, 1997). Top-down selection is also shown in the fact that when searching for an object in a scene, people first search at the likely locations for these objects. Search for an object at a non-predictable location is much slower than search for an object at a likely location (Meyers & Rhoades, 1978; Theeuwes, 1991c). Research on expert performance clearly shows the strength of top-down selection. Because of their attentional set, experts primarily focus on domain-specific stimuli whereas non-experts may also pay attention to other stimuli (Werner & Thies, 2000; De Groot, 1978; Chase & Simon, 1973a, 1973b; Reingold, Charness, Pomplun & Stampe, 2001; Groff & Chaparro, 2003; Pearson & Schaefer, 2005). These results suggest that intentions, goals and expectations guide selection and thereby perception. However, this top-down selection, ruled by intentions, goals and expectations may also introduce a fallacy. If road users are familiar with a road, they develop expectations about the presence of objects and how to behave. The fallacy may occur if these expectations are incorrect.

Martens and Fox (in press) already found that the visual glance duration to objects along the road decreases if people drive the same road several times. In a low-cost simulator, they had participants drive the same road several times over different days, thereby increasing the familiarity with the road. Only on the last day, a change was made in the lay-out of the road, in which a priority situation was changed into a give-way situation (with proper road markings and traffic sign). If people drove the same road numerous times they had more explicit expectations about what was represented on traffic signs than people who had driven the road only once. Besides decreasing glance duration, the effect of familiarity with the road was also reflected by an increase in average speed. Only 2 out of the 12 participants somehow noticed anything of the change. Of these 2, one participant only verbally responded to the change when actually crossing the intersection (so not in due time) and the other hardly responded and claimed to have noticed some change but did not remember what it was. Glance duration to the traffic sign that changed was as short as that of unchanged information. This suggests that even though the information is selected (glanced at), it is not processed to such a deep extent that it enables a response. These results support the idea that this is the fallacy of strong top-down information processing: With increased exposure to the same road, expectations are so strong that even though new information is selected, it does not result in a response since it does not fit the expectations. Although selected, it is not processed to a deeper extent that it allows a proper response.

Even though this previous study clearly showed that driving exactly the same road will result in this failure to repond to clearly visible stimuli, the question arises whether such an effect is more general in nature and can also occur when the road is not exactly the same. In other words, is it feasible that more general expectations that drivers have developed over time with a road lay-out in general may also induce 'the failure to apprehend'. If such an effect occurs then one may ask how one can break through these expectations allowing an adequate response. These two questions were studied in a driving simulator experiment.

11.2 Method

The central question was whether familiarity with the road resulted in 'the failure to apprehend' and whether this 'failure to apprehend' mainly occurred if drivers drove the same road several times or whether it also occurred if the road environment partly varied from one drive to the other. In order to study 'the failure to apprehend', a change to the road lay-out was introduced from one drive to the next. In this study, a normal road was changed into a No-entry road.

In order to control familiarity with the road, a condition was included in which the road environment always varied from one drive to the next. In these cases, the same road was used as a basis (with the same curvature, the same number and location of intersections and the same priority situation) but there were variations from one drive to the next. These variations were:

1. separated or non-separated lanes,
2. the type of buildings next to the road (high flats, houses or trees only) and
3. the distance from the road to the buildings (close or further away).

Some examples of the type of variations from one drive to the next are provided in Figure 11.2 to 11.4.

11.2.1 Participants

Altogether, 78 participants completed the experiment. All participants were recruited from the TNO participant data-base. Participants drove more than 5.000 kilometers per year and had had their driver's license for at least 5 years. Both men and women participated. All participants had normal or corrected to normal eye sight and were paid for their participation.

11.2.2 Apparatus

The experiment was conducted in the TNO driving simulator. During the experiment, a participant was seated in a fixed base mock-up of a BMW 318 (see Figure 11.1) and had all normal controls (steering wheel, accelerator, brake, car had automatic gear shift). Based on these controls, a mathematical vehicle model computed the momentaneous state of the vehicle model. Feedback of steering and gas pedal forces was given to the driver by means of electrical torque engines.

The momentaneous position and heading angle of the vehicle were transmitted via a supervisor computer to a SimFUSION Computer Generated Imaging (CGI) system, which computed the visual scene as seen from the position of the driver. This image was projected on a cylindrical screen in front of the mock-up with a forward angle view of 120 degrees. Participants also had a rearview mirror, a right mirror and a left mirror at their disposal.

Generating the visual images by the CGI takes about 66 msec, which yields a pure time delay in the simulated vehicle system that is not present in the real vehicle. A predictive algorithm has been added to the Vehicle Model (Hogema, 1992, 1993) to compensate for this delay. Thus, the output of the Vehicle Model consists of both the actual position and the CGI delay-compensated position.

The Sound System generated real-time sounds in the Mock Up of the driving simulator and provided the participant with sounds of the engine, tyres, driving wind and nearby other vehicles. The Sound System generated 3D-audio. The direction from which the participant in the mock up heard each sound component matched the location of the sound source in the simulated environment. For example, when a participant passed a car, the sound of that car first came from ahead, then gradually came closer and would finally end behind the mock-up.

The Motion Base PC received input from the Vehicle Model PC by means of an Ethernet communication link. The Motion Base PC transferred its input signals to commands for the Motion Base System. The Motion Base System was a 6 Degrees of Freedom (MOOG 2000 E) hexapod motion platform with the associated control equipment. The mock-up was placed on the platform; the RGB projectors and the projection screen were stationary.

11.2.3 Task

The task of the participants was to drive several drives on a road in the simulator. Participants were instructed to imagine that the drives were their daily drives home from work. They were instructed to drive as they normally would on such a road under these conditions. Participants were not instructed about what they would encounter, did not know that there would be a change in the last drive and they were not informed about the exact numbers of drives that they had to make.

11.2.4 Experimental conditions

Eight different conditions were used, with 9 or 10 participants per condition. For 6 out of the 8 conditions (Condition 1, 2, 3, 4, 5 and 8), participants made 19 drives, separated by 3 breaks. The first 18 drives were varied as indicated above (houses, flats, trees, separated driving lanes or not and distance of the objects along the road). Drive 19 included the change.

Examples of these varied drives are shown in Figure 11.2 through 11.4.

The road was always a 2-lane road with opposing traffic but on several drives the opposing traffic was physically separated by means of a wide mid section. There was no preceding traffic because this might affect the behaviour of the participant (speed, entering the No-Entry road). The road was a 2 km long road with some wide curves. There were three intersections present and there were no speed limits posted.

The last drive that participants made was a scenario with houses nearby the road with separated driving lanes (see Figure 11.3). At the second intersection, there was

a 'No-Entry' sign on the right side of the road (whereas there was no sign present at that location in any of the previous drives). It was this last drive that made the distinction between Condition 1, 2, 3, 4 and 5. In Condition 6, participants made one drive in total and in Condition 7 two drives.

Figure 11.1 BMW mock-up in the TNO Driving Simulator.

Figure 11.2 No separated driving lanes, houses far away.

Figure 11.3 Separated driving lanes with grass in the middle, houses nearby.

Figure 11.4 Separated driving lanes with grass in the middle, trees far away.

Altogether the conditions were (see also Table 11.1):

1) Condition 1 (control condition)
19 varied drives without a change at the end (There was not a No-Entry sign).

2) Condition 2
19 varied drives, the last drive showed the No-Entry sign.

3) Condition 3
19 varied drives, the last drive showed the No-Entry sign and 200m before the intersection, an in-vehicle voice warned the driver. The auditory message was: "Please note, traffic situation has changed" (In Dutch: "Let op, verkeerssituatie gewijzigd").

4) Condition 4
19 varied drives, the last drive showed the No-Entry sign and 200m before the intersection, an in-vehicle voice warned the driver. The auditory message was: "Please note, traffic situation has changed, No entry" (In Dutch: "Let op, verkeerssituatie gewijzigd, verboden in te rijden").

5) Condition 5
19 varied drives, the last drive showed the No-Entry sign and 200m before the intersection, a yellow traffic sign warned the driver reading: Please note, traffic situation has changed (In Dutch: Let op, verkeerssituatie gewijzigd).

6) Condition 6
1 drive, with the No-Entry sign.

7) Condition 7
2 drives, the second drive showed the No-Entry sign and a 200m before the intersection, a yellow traffic sign warned the driver reading: Please note, traffic situation has changed (In Dutch: Let op, verkeerssituatie gewijzigd).

8) Condition 8
19 similar drives (no varied environment), the last drive showed the No-Entry sign. Different from the other conditions, all 19 drives were exactly the same in their physical appearance, so the same type of buildings and the same road lay-out. All drives were driven in the road environment as shown in Figure 11.3. This condition was added in order to see whether the failure to respond would be stronger if people had driven the exact same road several times.

An overview of the conditions is shown in Table 11.1.

Table 11.1 Overview of the conditions.

Condition 1: Control condition, on drive 19, nothing was changed
Condition 2: In drive 19, the last intersection showed the traffic sign:
Condition 3: In drive 19, an in-vehicle voice was activated: "Let op, verkeerssituatie gewijzigd"* 200m before intersection. At the intersection itself, a traffic sign showed:
Condition 4: In drive 19, an in-vehicle voice was activated: "Let op, verkeerssituatie gewijzigd, verboden in te rijden" ** 200m before the intersection. At the intersection itself, a traffic sign showed:
Condition 5: In drive 19, 200m before the intersection, a sign similar to the following traffic sign was shown: Verkeerssituatie gewijzigd!   and at the intersection:
Condition 6: In drive 1, the following traffic sign was shown at the intersection:
Condition 7: In drive 2, 200m before the intersection, a sign similar to the following traffic sign was shown: and at the intersection:
Condition 8: In drive 19, the last intersection showed the sign:

This condition is the same as Condition 2, but here the 18 drives before had the same physical appearance in terms of road lay-out and type of buildings.

 * In English: Please note, traffic situation has changed.

** In English: Please note, traffic situation has changed, No Entry.

11.2.5 Procedure

Participants took part in the experiment in pairs. After reading the instruction, they filled in an informed consent. One participant was driving the simulator while the other waited in the entrance room. The participant was seated in the simulator, and all controls were explained. After this, the experimenter left the simulator room and participants could get used to driving the simulator in a practice drive. After every drive, the system would start up a new drive automatically.

After 6 drives, the participants would get a break. During the break of one participant the other was driving. Participants with only 1 or 2 drives did not come in pairs but sequentially.

11.2.6 Statistical analysis

For most of the statistical analyses of the data, an analysis of variance (ANOVA) was used with the between-participant factor Condition (8 altogether) and the within-participant factor Drive (if participants made more than one drive) and Road Section (the 2 kilometers before the intersection in which the traffic situation was changed were divided into road sections of 100m). The dependent variables were speed (km/h), deceleration (m/s^2) and number of entries into the 'No Entry road'. For post-hoc tests, the Fisher Least Significant Difference (LSD) was used. For pairwise comparisons, Chi-square tests were used.

11.3 Results

Since it was a between-participant study, it was important to test whether there were no initial differences in behaviour between the different participant groups.

11.3.1 Driving speed in normal drives

There was no initial difference in driving speed between the conditions in the first drive. This means that the different participant groups were comparable. The data of Condition 7 could not be included in this analysis since they only made one drive in which they encountered the No-Entry sign. This made the speed data incomparable to begin with.

When including all conditions with 19 drives (condition 1 through 5 and condition 8), an increase in speed was found over the 18 drives (main effect of Drive [$F_{(17,918)}$ = 1.97, $p < 0.01$]). Drive 19 was not included in this analysis since it included the drive with the No-Entry sign. Note that for condition 1 through 5, the road lay-out was varied from drive to drive. Over all 18 drives, the main effect of Condition [$F_{(5,54)}$ = 2.58, $p < 0.04$] showed speed differences between conditions. There was a 2-way interaction between Condition and Road section [$F_{(95,1026)}$ = 2.33, $p < 0.0001$],

indicating that the increase in speed during the drives was somewhat different for the different conditions. This interaction is shown in Figure 11.5. This figure shows that for Condition 1 and Condition 8, the increase in driving speed over all 18 drives was stronger than in other conditions.

11.3.2 Number of entries

Since the main goal of the traffic sign was to prohibit participants entering the road, it is interesting to assess the number of people who actually entered the road (which was forbidden) irrespective of their driving speed. These results are shown in Table 11.2.
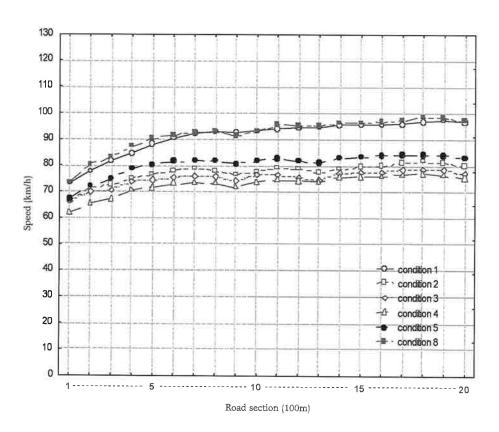
Figure 11.5 The interaction between Condition and Road Section over the first 18 drives.

Table 11.2 The number and percentage of entries of the No-Entry road for the different conditions.

	# of participants	# entering
Condition 1: Control condition, in drive 19, nothing was changed	10	10 = 100%
Condition 2: In drive 19, the last intersection showed the sign:	9	5 = 56%
Condition 3: In drive 19, an in-vehicle voice was activated: "Let op, verkeerssituatie gewijzigd"* at 200m before intersection. At intersection the following sign:	10	0 = 0%
Condition 4: In drive 19, an in-vehicle voice was activated: "Let op, verkeerssituatie gewijzigd, verboden in te rijden" ** at 200m before the intersection. At intersection the following sign:	9	0 = 0%
Condition 5: In drive 19, 200m before the intersection, a sign similar to the following sign was shown: Verkeerssituatie gewijzigd ! and at the intersection:	10	1 = 10%
Condition 6: In drive 1, the following sign was shown at the intersection:	10	4 = 40%
Condition 7: In drive 2, 200m before the intersection, a sign similar to the following sign was shown: Verkeerssituatie gewijzigd ! and at the intersection:	10	1 = 10%
Condition 8: Participants encountered the same road 18 times in a row. In drive 19, at the last intersection, the following sign was shown:	10	3 = 30%

* In English: Pleas note, traffic situation has changed.

** In English: Please note, traffic situation has changed, No Entry.
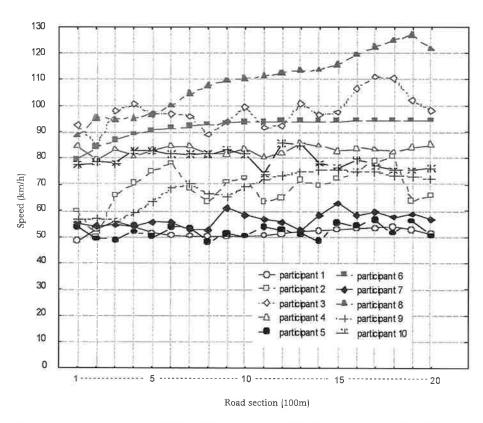
Figure 11.6 Speed behaviour for Condition 1 (control condition) in drive 19. At road section 20, there was no No-Entry sign present.

In the control condition, 100% entered the road, which was to be expected since the No-Entry sign was not present. In case of the No-Entry situation, there were several occasions of 'the failure to apprehend'. When 19 varied drives were made, 56% of the participants still entered the road with the No-Entry sign only (Condition 2). This was 40% for the condition in which it was the first time people drove this road and were confronted with the No-Entry sign only (Condition 6). So even if people drove the road for the first time, there was a 'failure to apprehend'. Altogether, quite some errors were made, entering the No-Entry road.

In Condition 8, participants encountered the exact same road 19 times. Here, 30% entered the No-Entry road. Although this percentage is still high, it is not higher than in the conditions with the varied drives. This indicates that the failure to respond is not the mere result of being familiar with that specific road. Apparently the road design itself leads to the failure to respond even when driving the road for the first time and irrespective of the exact appearance.
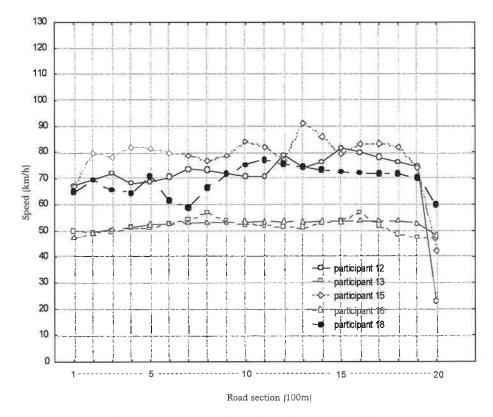
Figure 11.7 Speed behaviour for Condition 2 in drive 19. At road section 20, there was a No-Entry sign present.

In case of an additional road sign before the No-Entry sign (Please note, traffic situation has changed; Condition 5 and 7), 10% failed to respond and entered the road. Again, irrespective of whether they drove the road 18 varied drives before (Condition 5) or only once before (Condition 7). In case of an in-vehicle voice, 0% entered the No-Entry road. This was the case for the in-voice message that just told them that there was a change (Condition 3) or also pointed out what had been changed (Condition 4).

A Pearson Chi-square non-parametric test showed a main effect of condition on number of participants that entered the road [χ^2 (7) = 37,99, p < 0.0001]. Most errors are made in Condition 2 (Just No-Entry sign after 19 drives with variation), Condition 6 (first drive No-Entry sign) and Condition 8 (Just No-Entry sign after 19 drives without variation). No errors were made in the conditions with the voice-messages (Condition 3 and 4) and one error was made in Condition 5 ('No-Entry sign' and additional sign after 19 drives) and Condition 7 ('No Entry sign' and additional sign after 2 drives).
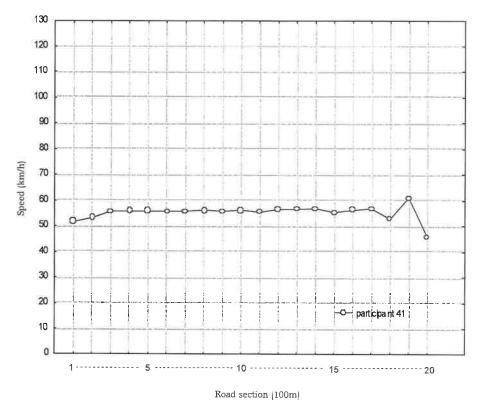
Figure 11.8 Speed behaviour for Condition 5 in drive 19 (yellow additional sign and a No-Entry sign).

These data clearly shown that there is no indication that 'the failure to apprehend' occurs more frequently after more drives, so expectations built with familiarity cannot explain this. Also, the occurrence of 'the failure to apprehend' is comparable between the condition with the variation in the lay-out of the road and the condition without any variation.

11.3.3 Driving speed in the last drive (No-Entry sign)

In terms of speed behaviour, drive 19 was the most interesting drive in the experiment since it included the change in the No-Entry road. For Condition 6, the drive with the No-Entry road was their first drive (simulating people who did not have any experience with this road yet but did encounter the No-Entry sign). For Condition 7, this was their second drive (simulating people who did have some expectations based on the drive before, but familiarity is much weaker). In Condition 1, the control condition, people were not confronted with a No-Entry situation.
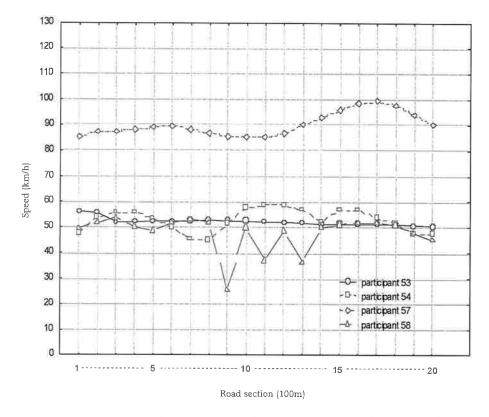
Figure 11.9 Speed behaviour for Condition 6 in drive 1 (No-Entry sign already on the first drive).

Therefore, the speed behaviour of participants in Condition 1 can be taken as the behavioural baseline for participants that do not select or do select but do not deeply process the No-Entry information, leading to 'the failure to apprehend'.

The adequate response to the No-Entry sign would either be to come to a complete stop (speed 0 km/h), or to turn left or right on the intersection. In order to make a left or a right turn, participants had to drastically reduce their speed but did not have to come to a complete stop. In order to make a fair comparison between adequate and inadequate responses, the speed on road section 20 (at the No-Entry sign) was manually replaced with the value 0 (speed 0 km/h) if one turned left or right.

When analysing the speed data, it is most useful to make a distinction between participants that showed the correct behaviour (stopped or made a turn) and those who did not (entered the No-Entry road). For those participants that did not
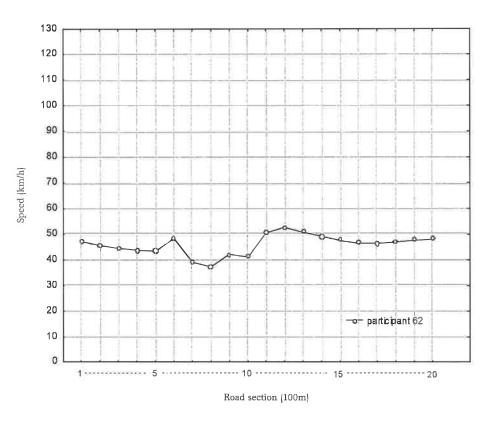
Figure 11.10 Speed behaviour for Condition 7 in drive 2 (yellow additional sign and a No-Entry sign on the second drive).

show the correct behaviour, it is interesting to investigate whether there was any change in speed. A decrease in speed may indicate that there was at least some response.

Since the number of participants that did not show the correct behaviour varied from condition to condition, it is not possible to statistically analyse the data. Therefore, the data are plotted in graphs for a qualitative analysis.

First of all, Figure 11.6 shows the data for the control condition. These data are illustrative for participants who did not see the No-Entry sign at all (since in this condition there was no such sign).

What can be seen from Figure 11.6 is that there are some participants that do seem to show some decrease in speed at the last road section(s). This may be the result of participants paying attention to the intersection. This is primarily the case for
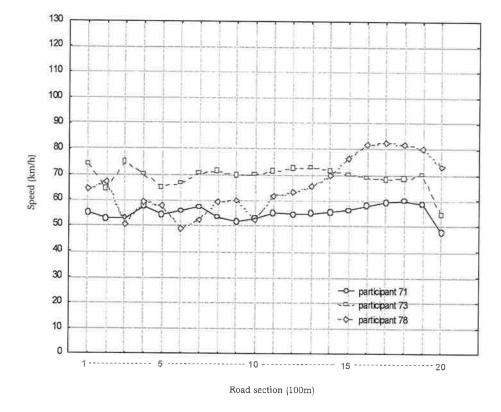
Figure 11.11 Speed behaviour for Condition 8 in drive 19 (a No-Entry sign and no variation from drive to drive).

participant 2, 3 and 8. The decrease in speed is similar to the decrease in speed in response to the first intersection (road section 7).

As we have already seen, in Condition 2 (just the No-Entry sign after 19 drives), there were five participants that did not show the correct behaviour. The speed data for the last drive for those participants that did not stop or turn are plotted in Figure 11.7.

What is shown in Figure 11.7 is that there are at least two out of the five participants (participant 12 and 15) that do show a strong decrease in speed. Participant 18 alread showed a similar decrease at the other intersection (road section 7) so this is not the result of the No-Entry sign.

Condition 3 and 4 only included participants that showed the correct behaviour.
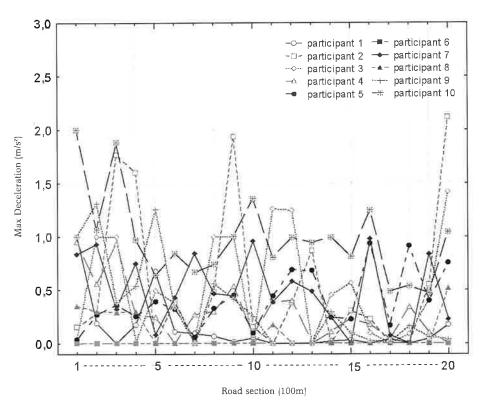
Figure 11.12 Maximum deceleration for Condition 1 (control condition) in drive 19. At road section 20, there was no No-Entry sign present.

Figure 11.8 shows the results for Condition 5. There was only one participant that did not show the correct behaviour.

Figure 11.8 shows that there is some form of response in terms of a small decrease in speed that is stronger than speed changes found on the first intersection.

Figure 11.9 shows the results for Condition 6. There is no effect of the No-Entry sign. Participants 53 does not show any response, and participant 54, 57 and 58 may show some effect, but the speed is not lower than on any of the preceding road sections. Therefore this is most likely not the result of the presentation of the traffic sign.

Figure 11.10 shows the results for Condition 7. Condition 7 only contains one participant that does not show the correct behaviour. There does not seem to be any effect on the speed.
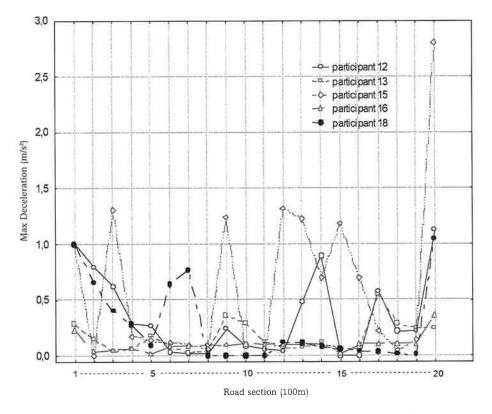
Figure 11.13 Maximum deceleration for Condition 2 in drive 19. At road section 20, there was a No-Entry sign present.

Figure 11.11 shown the results for Condition 8.

Two participants (participant 71 and 73) seem to show some effect on speed. Although this could also be claimed for participant 78, the decrease in speed is not much higher than has been found on previous road sections.

11.3.4 Maximum deceleration

Besides the driving speed just before the No-Entry sign and actual access of the No-Entry road it is interesting to study the decelerations that were shown. It might have been that in some conditions, participants decelerated more than in other conditions. The stronger the deceleration level, the higher the chance that this is the result of drivers noticing the sign at the last moment. The higher the deceleration the stronger one was braking.
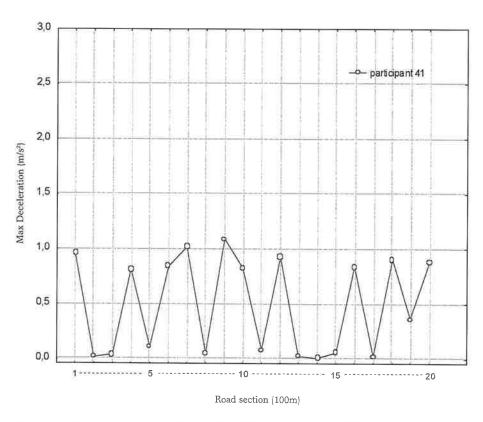
Figure 11.14 Maximum deceleration for Condition 5 in drive 19 (yellow additional sign and a No-Entry sign).

The maximum deceleration levels are provided for all participants that entered the No-Entry road.

Figure 11.12 shows that in the control condition, the maximum deceleration at road section 12 does not exceed any maximum deceleration on prior road sections. Therefore this will also be a criterion for 'the failure to apprehend'.

Figure 11.13 presents the data for the five participants in Condition 2 that do not show the correct behaviour. In this condition, with only the No-Entry sign in drive 19, there are some indications of a deceleration response despite the fact that they did not come to a stop or made a turn. Participant 15 showed a maximum deceleration that was far stronger than any of the maximum deceleration levels on previous sections. For the other participants, the effects are not so clear.
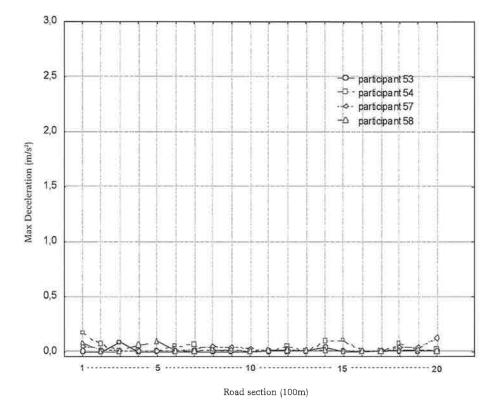
Figure 11.15 Maximum deceleration for Condition 6 in drive 1 (No-Entry sign already on the first drive).

In Condition 3 and 4, all participants showed the correct behaviour. Figure 11.14 presents the results for Condition 5 (No-Entry sign and an additional yellow sign pointing to the change). Participant 41 did not show a maximum deceleration level on road section 20 that was higher than on the previous road sections.

Figure 11.15 shows the maximum deceleration levels for the four participants in Condition 6. In Condition 6, participants were confronted with the No-Entry sign at drive 1. There are no clear deceleration patterns for any of the four participants. Therefore there are no indications that there was a response to the traffic sign.

Figure 11.16 shows the results for participant 62 in Condition 7, the one participant that did not show the correct behaviour. In Condition 7, participants were confronted with the No-Entry sign and the additional yellow sign on drive 2.
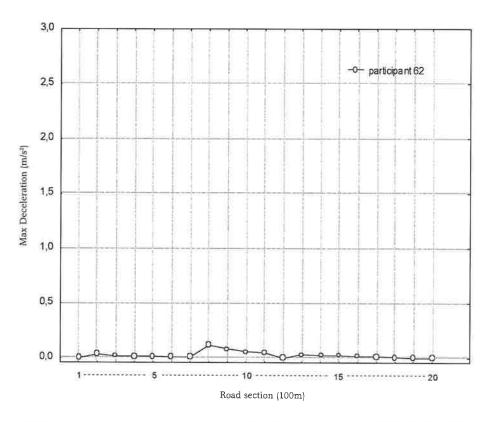
Figure 11.16 Maximum deceleration for Condition 7 in drive 2 (yellow additional sign and a No-Entry sign on the second drive).

There is no indication of any strong deceleration response of the participant as a response to the signs that were shown.

Figure 11.17 presents the data for the three participants of Condition 8 that did not show the correct behaviour. For participant 73, there seems to be an indication that there is a maximum deceleration that points to a response to the traffic signs that are shown. The maximum deceleration levels for participant 71 and 78 do not exceed the levels that are also shown at previous road sections.

11.4 Conclusions

11.4.1 Effect of familiarity

In the beginning of this report, we assumed that people who drive the same road several times will become so familiar with the road environment that they respond less adequately to a change due to the expectations they have built up.
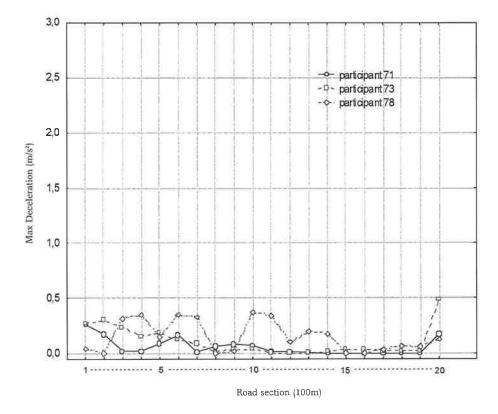
Figure 11.17 Maximum deceleration for Condition 8 in drive 19 (a No-Entry sign and no variation from drive to drive).

In order to test this, the behaviour as found in Condition 8 (19 drives on exactly the same road, No-Entry sign only) was compared to the behaviour shown in Condition 6 (1 drive only, No-Entry sign only). The mean driving speed in Condition 6 (first drive) was lower than the mean speed of Condition 8 in drive 19, but this was the result of an increase in driving speed over numerous drives as was found in this experiment. The current study showed that this increase in driving speed with more drives is found irrespective of whether it is the exact same road that people drive or whether there are some variations in its appearance.

In the last part of the drive (just before the No-Entry sign), there was no difference in driving speed between these two conditions. In both conditions, the number of errors of people entering the road was fairly high (40% for first drive and 30% for the 19th drive). Based on this information, we claim that it is not the familiarity with the road per se that leads to the failure to adequately respond to the No-Entry situation. Even if people did not drive the road before, quite some participants failed

to respond adequately. Apparently the road design is so prototypical that strong expectations are triggered and even drivers unfamiliar with the road do not expect a No-Entry road. This is confirmed by the speed behaviour data and the maximum deceleration levels of participants that entered the road. For the four participants that drove the road for the first time (no familiarity), the speed at this intersection was not lower than the speed on any preceding road section in drive 19. Therefore the assumption is that there really was no response at all to the No-Entry sign. For the three participants that drove the same road 18 times before (familiarity), two participants seem to show some reduction in speed. The maximum deceleration levels generally seem to confirm these findings. There clearly is no worse response when participants are familiar with the road compared to participants that drive the road for the first time.

11.4.2 Effect of variation in the road environment

The question was whether there would be a difference in response to the No-Entry road if people have driven the exact same road numerous times or if they have driven a similar road but with variations in its appearance (same traffic rules but with different buildings, trees, different road widths and different distance to the buildings and trees).

In the last drive, the driving speed for Condition 8 (exact same road lay-out every drive) was not significantly higher than that of Condition 2 (variation in road lay-out from drive to drive). For the 19 varied drives with only one No-Entry sign on drive 19, 56% of the participants entered the No-Entry road. This was 30% of the participants for the condition with 19 exact same drives and only one No-Entry sign on drive 19. This indicates that even though the level of errors was high in both conditions, people responded even less adequately to a road change if the road lay-out was varied from one drive to the other. The number of participants that entered the road but did show some response in terms of a decrease in speed or a clear deceleration was equal in both conditions. Both conditions included one participant that showed a decrease in speed despite the fact that their reponse was not adequate.

The results indicate that there are some differences in behaviour. With the varied drives, people even tend to show less adequate behaviour compared to the people who drive the exact same road numerous times.

11.4.3 Countermeasures

Now the question is what can be done to break through this failure to respond. In order to investigate this, extra countermeasures were included into the experiment in order to assess the effects.

One of the countermeasures was placing an additional yellow traffic sign ("Traffic situation changed"), a measure that is often taken in the Netherlands in case of changed situations. In order to assess the effect of this additional sign, we compared Condition 5 (19 varied drives, the No-Entry sign and the yellow additional traffic sign) to Condition 2 (19 varied drives and the No-Entry sign only). With the additional sign, 10% entered the road whereas this was 56% for just the No-Entry sign. So there is better performance with the additional sign, although 'the failure to apprehend' is still found.

If we assess the effect of the in-vehicle systems, we compare Condition 3 (voice warning about changed situation) and Condition 4 (specific voice warning about changed situation AND not entering the road) with Condition 2 (only the No-Entry sign). The in-vehicle messages were the only conditions in the experiment that resulted in 100% adequate responses. The number of people that entered the road in the condition with the No-Entry sign only was 56%. This was 0% in the conditions with the voice messages.

These results indicate that there is indeed a better response with additional counter-measures. Best results are obtained with in-vehicle auditory messages. Interestingly, there is no difference between the non-specific in-vehicle message and the specific one. Apparently, the non-specific auditory message warns the driver sufficiently in order for him/her to pay attention to visual information in the environment (the No-Entry sign). It is not necessary to specifically tell the driver what the new situation is.

11.5 Discussion

In a previous study (Martens & Fox, in press) we found that there are risks involved in driving the exact same road several times. That study showed that familiarity with the road makes road users develop expectations and in case of incorrect expectations (a change in the priority situation) there were strong negative consequences due to the failure to respond to relevant information, also called 'the failure to apprehend'. However, the current study reveals that these negative consequences of driving the same road several times are not the direct result of road familiarity.

In the current study, we found that 'the failure to apprehend' is also found in case of driving a varied road or even when driving the road for the first time. This indicates that there are situations in which 'the failure to apprehend' is not the mere result of prior exposure to that particular road. Even though it was shown that quite some errors were made in case of a change to a previously encountered traffic situation,

the errors seemed to be the result of incorrect expectations induced by the road design itself rather than the result of expectations that people developed while driving this road several times (road familiarity). When the road appearance was varied from drive to drive, behaviour was similar to the condition in which one encountered the exact the same road numerous times.

Apparently a road lay-out may activate specific schemata without having driven that specific road before. By having encountered similar roads in the past, drivers have developed schemata that dictate what to expect on these types of roads and how one should behave. Since schemata are characterised by strong top-down control there is not much room for bottom-up selection of information. Information that does not fit the schema will either not be selected or it will not be sufficiently processed. This explains why there was no response to the No-Entry sign: the bottom-up features were not strong enough to break through this strong top-down control. For some participants, there were behavioural indications that there was some (although not the correct) response. A slight decrease in speed for instance indicated that the information was selected and processed to some degree. Presumably, there was no correct response since the top-down control by means of schemata was stronger.

In order to increase the chance of a response in these circumstances, two approaches can be chosen. One approach lies in increasing the bottom-up control, the other in decreasing the top-down control.

The first approach is to increase the strength of the bottom-up features of in this case the No-Entry information. This is done in the experiment by placing an additional sign. The colour of the additional sign was rather conspicuous in its surroundings (yellow sign) and by having two new elements in the surroundings instead of just one, bottom-up control was increased. The idea behind such an additional sign, that is often used for indicating a changed traffic situation in the Netherlands, is that people will pay more attention to monitor what has changed. The additional sign is supposed to be able to change the way drivers scan their surroundings. However this assumes that the information from this additional sign is actually selected and sufficiently processed. The current experiment showed that although the additional sign did improve behaviour, there were still cases of 'the failure to apprehend'. Only by means of an auditory message, there were no cases of 'the failure to apprehend'. It may very well be that the additional sign was not selected or not sufficiently processed in all cases, whereas the auditory message with strong bottom-up features was always selected and fully processed.

A second option for reducing 'the failure to apprehend' is to decrease the top-down control. This can be done by avoiding that schemata are developed. As long

as a specific road-layout is always accompanied by specific rules or prototypical behaviour, schemata will develop. In order to avoid the development of schemata with strong top-down control, roads should be designed very differently than is currently being done. Much more variation would need to be used, for instance by varying the priority situation within one type of road, by applying different rules to the same type of road, and by using the same type of road lay-out for different types of roads and behaviour. Simply applying some variation in the road surroundings is not sufficient, as the present experiment has shown.

Even though both options offer the possibility to reduce the occurrence of 'the failure to apprehend', the consequences of applying either one are quite different. The consequence of strengthening the bottom-up features to indicate a unique, changed or deviant situation would be to design the situation in a way that is most different from the former or normal situation (different markings, traffic signs, pavement, etc). The consequence of decreasing the top-down control would be that a completely new way of designing roads would need to be applied. In order to guarantee sufficient variation, all road authorities would need to co-operate and agree upon where to implement what type of situation. By avoiding top-down control, driving would be brought back completely to a knowledge-based type of behaviour, requiring a lot of attentional resources. The efficiency of task performance based on activated schemata will thereby be lost. Also, expectations will also develop if a driver becomes familiar with a specific road. Therefore, the most plausible and efficient option would be to strengthen the bottom-up features of the information that points to the changed or deviant situation.

12

Change detection in road environments: Where do we look and what do we perceive?[5]

12.1 Introduction

Change Blindness is a phenomenon that has been studied for a number of years (e.g. Mack & Rock, 1998; O'Regan, Rensink & Clark, 1999; Simons & Chabris, 1999; Simons, Franconeri & Reimer, 2000; Rensink, O'Regan & Clark, 1997; Rensink, 2000a; Hollingworth & Henderson, 2002; Rensink, 2002; Simons, 2000). Change Blindness has been defined as 'the inability to spot changes to objects, photographs and motion pictures from one instant to the next' (for a review see Simons & Levin, 1997), and involves the inability to report, detect or see changes in visual stimuli that are obvious once they are pointed out.

In classical Change Blindness tasks, participants view a scene, followed by a disruption. This disruption can be an eye movement (e.g. Grimes, 1996; Henderson & Hollingworth, 1999a, 2003b), a blink (e.g. O'Regan, Deubel, Clark & Rensink, 2000), a blank screen (e.g. Simons, 1996; Rensink, O'Regan & Clark, 1997), a sudden 'mudsplash' on the screen (comparable to a sudden mudsplash on a car windshield) (e.g. O'Regan, Rensink & Clark, 1996), motion picture cuts (e.g. Levin & Simons, 1997; Simons, 1996) or a physical occluder (e.g. Simons & Levin, 1998). After the disruption, a modified version of the scene is shown, in which something has been changed. In most cases, participants are instructed to look for that change. This type of experiment has shown that participants are surprisingly bad at detecting even large changes to photographs or displays after a brief interruption (Simons & Mitroff, 2001).

It is tempting to explain Change Blindness by claiming that people do not look at the element that changes. Hollingworth, Schrock and Henderson (2001) found that changes were rarely detected until after they had been fixated. O'Regan, Deubel, Clark and Rensink (2000) found that Change Blindness decreases if people look directly at the change. However, they also found that in many cases, fixating the information still resulted in Change Blindness. Over 40% of the participants did not notice the change even though they were looking directly at it.

An interesting fact emerging from Change Blindness studies is that this phenomenon is not only found in artificial scenes, but also in photographs and movies (a.o. Blackmore, Brelstaff, Nelson & Troscianko, 1995; Grimes, 1996; McConkie & Currie, 1996; O'Regan, Rensink & Clark, 1996; Pashler, 1988; Rensink, O'Regan & Clark, 1997; Simons, 1996) and even in real world situations (a.o. Simons, Chabris, Schnur & Levin, 2002; Simons & Levin, 1998; Levin, Simons, Angelone & Chabris, 2002). In dynamic scenes such as movies, people are not good at noticing the changes from one scene to the next. Simons (1996) and Levin and Simons (1997) asked participants to watch a movie with so-called editing mistakes. Changes included people wearing different clothing from one shot to the next, or objects changing location.

Many of these changes were not detected by observers. To study the phenomenon of Change Blindness in a real world setting, Simons, Chabris, Schnur and Levin (2002) used partly staged but real life situations. For instance, an experimenter carrying a basketball would approach a naïve pedestrian, and start a conversation. During this conversation, a group of students would pass between the experimenter and the pedestrian and secretly take the basketball away. Only a few pedestrians noticed the disappearance of the basketball. In another experiment, Simons and Levin (1998) had an experimenter approach a naïve pedestrian on the street and ask him or her for directions. While having this conversation, two people carrying a large door walked in between the pedestrian and the experimenter, shortly blocking the pedestrian's view of the experimenter. During this short period of time, the experimenter was replaced by a second experimenter, who wore different clothes. About half of the participants reported not to have noticed the change, even though they actively interacted with both the first and the second experimenter! Another real life study (Levin, Simons, Angelone & Chabris, 2002) also confronted participants with an unexpected person change when two people carried a door in between the participant and the experimenter (just like Simone and Levin, 1998). 38% of the observers failed to see the person switch. When the person switch took place after an experimenter had approached a participant to ask him/her to take his photograph, 53% missed the person change. In case of a person change after the experimenter duck back behind a counter, 75% of the observers failed to see the person change.

One explanation for this strong phenomenon is that the changes were made to items that were not relevant for the task at hand and that participants were therefore not paying attention to these items. Research has shown that even changes that are central to the scene, and therefore assumably attended, are often missed (for example, see Angelone, Levin & Simons, 2003; Levin & Simons, 1997; Simons & Levin, 1998; Simons, Chabris, Schnur & Levin, 2002). An explanation for Change Blindness in case of a central object may be that although centrally located, it is not relevant for the task at hand. Various studies have shown that Change Blindness is relatively low, or responses are relatively fast, if the change is related to the specific context of the scene. Richard, Wright, Ee, Prime, Shimizu and Vavrik (2002) showed that in car driving scenes, driving related changes lead to faster responses than driving-unrelated changes. This was also found by Groff and Chaparro (2003) and Pearson and Schaefer (2005). Change Blindness is also assumed to be highly related to (in)attention to the changed object. In this respect the term 'Inattentional Blindness' is also highly related. Inattentional Blindness refers to the tendency not to see unattended objects (Mack & Rock, 1998). The difference with Change Blindness is that in Inattentional Blindness, there does not need to be a specific change. In this respect, Hochberg (2007) claims that the term 'Inattentional Disregard' is more appropriate than the term Inattentional Blindness. Additional tasks, such as the

Working Memory Span Test (Baddeley et al., 1985) or a phone conversation, are found to decrease change detection in driving-related Change Blindness paradigms (Richard et al., 2002; McCarley, Vais, Pringle, Kramer, Irwin & Strayer, 2004). Also, older drivers (who are known to have specific attentional problems) have found to be more prone to Change Blindness in driving related changes than younger drivers (Caird, Edwards, Creaser & Horrey, 2005; McCarley et al., 2004; Pringle, Irwin, Kramer & Atchley, 2001). Many researchers have shown a relation between attention and Change Blindness (Pringle et al., 2001; Richard et al., 2002; Rensink, O'Regan & Clark, 1997; Scholl, 2000; Simons, 2000).

Some studies have shown that there may be implicit processing of visual stimuli without explicit awareness of a change. For example, fixation duration is affected by changes in a scene, even without observers being able to report the change (Hollingworth, Williams & Henderson, 2001; Ryan, Althoff, Whitlow & Cohen, 2000). This increase in fixation time for changed items has been reported in a number of other studies (Hollingworth & Henderson, 2002; Karn & Hayhoe, 2000; Hayhoe, Bensinger & Ballard, 1998; Ryan & Cohen, 2004).

These findings illustrate that it may indeed be the case that information is processed without the observer being able to explicitly report it. If this is indeed the case, then Change Blindness experiments, in which only a verbal response is required for reporting a change may be too limited. Another way of processing change perception is to study whether there is some effect of the presented information on other tasks. By studying so called priming effects, one can examine the effect of the presentation of a stimulus on the processing of a subsequent stimulus. This provides a suitable method for examining the fate of processed stimuli that do not lead to explicit reports. Chun and Jiang (1998) showed that presented information may directly influence performance without explicit reports. Participants found a target more efficiently when they had seen the search array before, even when they did not recognise the display. This represents a form of implicit learning or positive priming effect (Lewicki, Hill & Czyzewska, 1992; Reber, 1989; Stadler & Frensch, 1998). Jacoby and Dallas (1981) showed that prior presentation of a word had a large effect on its later recognition at extremely brief presentations, irrespective of whether participants remembered this prior presentation. They called this effect perceptual learning.

The current study focuses on Change Blindness in dynamic scenes when the items that change are task relevant. One hypothesis is that type of change induced affects the occurrence of Change Blindness, with larger changes leading to a lower level of Change Blindness. Another hypothesis was that there is a positive relation between glance duration and change awareness. Besides explicit Change Blindness measures and glance duration we also measured the ability to use presented information in

another task despite the ability to verbally report it. A third hypothesis was that raising attention by playing an auditory warning just before the change would decrease Change Blindness. The study was performed by having car drivers watch video films showing a driving scene and making changes to traffic signs from one drive to the next.

It is important to note that the current Change Blindness study is different than most Change Blindness studies. In most Change Blindness studies, the change is introduced after a short visual disruption, such as a blank screen or an eye blink. However, in real life settings, the change will not be introduced from one instant to the next, but rather after longer visual disruptions. One example of such a real world Change Blindness setting with a longer visual disruption is provided by Beck, Levin and Angelone (2007). They describe the example of a person sitting in the waiting room of a doctor's office reading a magazine. The person looks up from the magazine at the scene in front of him for a few seconds and then, just as a man is walking through the room, looks back down at the magazine. Somewhat later, the person looks back up at the room and a nurse asks if the man in the room took anything from the room. This is an example of a Change Blindness study in a real world setting. If one has been reading in the magazine for a while, the visual disruption between the room before and the room after is rather long. This is exactly the criticism of Smilek, Eastwood, Reynolds and Kingstone (2007) to brief visual disruptions. They claim that experimental Change Blindness tasks using photographs with changes from one instant to the next are relatively artificial and that peoples' performance in these tasks might not be representative of their behaviour in the real world. They plead for studying Change Blindness in more naturalistic tasks in real world situations.

In our study, a change was introduced from one video film to the next and not from one shot to the next. The video film showed a drive, filmed from a driver's point of view. Participants watched this video film of the drive, with a particular sign A being shown. They watched this film five times, and the sixth time, the video film showed another sign at the location where sign A was shown in prior 'drives'. In this sense, there is a relatively long time interval between viewing sign A in the first films and sign B in the last film.

12.2 Method

12.2.1 Participants

140 participants took part in this study. However, because of problems with the calibration of the eye movement equipment, data from only 131 participants were of sufficient quality to be included in the analyses. The group consisted of 56 males and 75 females, with an average age of 32 (ranging between 19 and 62 years of age).

All participants possessed a driver's licence, and had been driving for the last year (> 5000 kilometers). The group of 131 participants was randomly divided over five different conditions, but age and gender were balanced in the different conditions (see 12.2.4 for a description of the conditions).

12.2.2 Task
Video

The participants' main task was to watch a video of various driving scenes. Participants were seated in front of a television monitor. The videos contained real scenes filmed in an urban area, from the car drivers' viewpoint. The route filmed is shown in Figure 12.1.

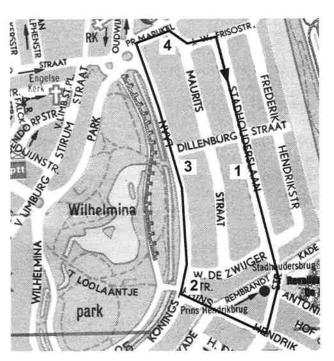**Figure 12.1** The experimental route painted in black.

Participants' task was to watch the video as if they were the driver of the car. They were told that they had to pay attention to everything they normally pay attention to when they are driving.

The four numbers displayed in Figure 12.1 indicate the location of four traffic signs that were present along the route, together with numerous other traffic signs. These

four traffic signs are presented in Figure 12.2. Traffic sign 1 was the indication of driving on a priority road (1), traffic sign 2 indicated two minor side roads (2), traffic sign 3 indicated a minor side road from the right hand side (3) and traffic sign 4 indicated that one had to yield to a priority road (4). Note that traffic sign 3 in Figure 12.2 was the critical traffic sign, which changed into another traffic sign in the last drive.
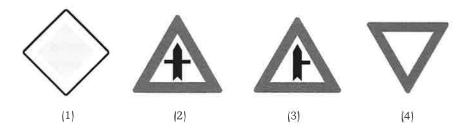

Figure 12.2 Four of the traffic signs used along the experimental route.

Participants were instructed that in the last drive (they did not know how many drives there would be) the video would be stopped at some point in time and that it was their task to indicate whether they had seen any change and if so what it was. This change was implemented by replacing one traffic sign with another, from one drive to the next. This was done by physically changing the sign in the outside world and recording the drive with the new sign. This was done to avoid any side-effects resulting from artificially inserting signs into the scene after the recordings (e.g. with software). Therefore, we simulated a situation in which a driver encountered a certain traffic sign on a particular drive and encounters another (sign change) traffic sign in a subsequent drive. All traffic signs used were official Dutch traffic signs. The original sign was not visible in this last drive since it was replaced by a new one. Therefore, the set-up of this experiment is different to most Change Blindness studies in which the change occurs during a blink, a short blank interval or a saccade. The change here was implemented from one drive to the next, so from one complete video to the next. Participants were told that the change would be traffic related and that it would be presented just before stopping the video. They were explicitly told that it would not be a change to an item that you do not normally pay attention to as a driver, such as a change to the colour of the door of a house. They were also instructed that they had to pay attention in all drives in order to notice the change. They were not informed that the experiment was focusing on traffic signs. Since the drive around the block was always recorded in the same physical environment, the number of traffic signs present from one drive to the next was always the same.

Traffic sign identification task

As well as measuring Change Blindness, which is an example of explicit perception, implicit change detection was also measured. Implicit perception of changes was measured by examining glance duration to traffic signs. In addition, participants also completed a traffic sign identification test. The question was whether there was better identification for traffic signs that were presented in the study if they were briefly presented at a later stage. This was the second task that participants had to perform, a traffic sign identification task. If participants who are Change Blind are better at identifying the changed sign compared to participants who had not been confronted with that sign in the video, this would be an indication of implicit processing. Also, longer glance duration to the changed sign in case of Change Blindness can indicate implicit perception.

In order to determine a personal threshold for the traffic sign identification test, a pre-test was done before participants watched the driving videos. Participants were seated in front of a computer screen which was occluded by means of a shutter. By briefly opening the shutter, a pictogram became visible. After the brief presentation, a mask was shown at the location of the presented pictogram. Participants' task was to indicate what pictogram was shown. A forced choice paradigm was used by asking participants to select one of two possible descriptions for each traffic sign. Two examples are shown in Figure 12.3.

a) Prohibited to smoke
b) Prohibited to bring food

a) Fragile
b) Inflammable

Figure 12.3 Two examples of the pictogram identification test with two answer categories.

The first pictogram was always visible for 60 msec. Presentation times were then decreased or increased depending on the participant's response. The threshold that was calculated aimed for an identification rate of 60%, somewhat above change level but with chances for improvement. 50 pictograms were used to determine the personal threshold of each participant. The thresholds that were calculated by means of the pictogram identification task varied between 5 msec and 98 msec, with

a mean presentation time of 33 msec. These values were used later for the traffic sign identification task. This method for calculating a personal presentation threshold is described by Snoeren and Puts (1997) and is an extension of the Quest method (Watson & Pelli, 1983).

12.2.3 Procedure

After performing the pictogram identification task, participants were seated in front of the television monitor. Glance direction and duration was measured using the Tobii X50 eye tracker. This equipment has an accuracy of 0.5 degrees, with binocular tracking at a rate of 50 Hz. The experimental set-up is presented in Figure 12.4.
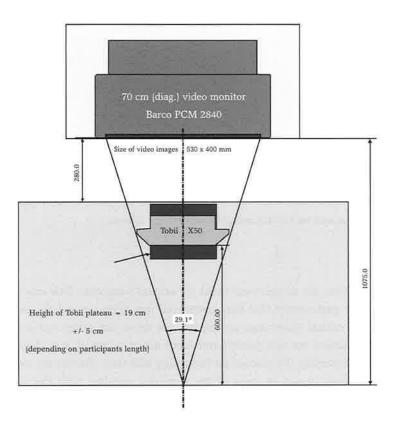

Figure 12.4 The experimental set-up.

Participants watched the driving videos after the automatic calibration process for the Tobii equipment. An example of a participant watching a video is provided in Figure 12.5.

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Figure 12.5 A participant watching the video. The Tobii equipment is visible just below the television monitor with the two dots being the infrared light sources.

After every drive, the screen went blank for around 5 seconds. This was used as an indication for participants that they completed one drive around the block. After 'passing' the critical traffic sign during the last drive, the video was stopped, the image was blacked out and participants were asked to report any changes to the scene. After reporting the change (or indicating that they did not see any change) participants were seated in front of the computer monitor with the shutter and performed the traffic sign identification test. Using each individual's own personal threshold, several traffic signs were briefly presented to participants and again they had to choose between two alternative answers. This test included 10 traffic signs, some of which were part of the scene shown to participants in the videos. Ten signs were used in the test in order to include signs that participants encountered and to include signs they did not encounter in the video. Many more signs would have increased the time between the presentation of the sign in the scene and the test. The traffic sign identification test started about 20 seconds after the video was stopped.

At the end of the experiment, the experimenter explained what the change had been, giving participants the chance to state whether they had seen the change. In cases where this happened, 'correct detection' was noted.

12.2.4 Experimental design

The experiment had a between-participant design and included five conditions. The conditions differed in the type of change that was presented. In all conditions, participants watched six drives on video. The first five drives were slightly different from drive to drive in terms of the presence of other traffic, number of pedestrians etcetera. However, they were similar in terms of location and lay-out of streets, road markings, priority situation and traffic signs. This was comparable to the variation that would be present if a road user drove the same piece of road at different times of the day or different days. The first five drives were the same for all conditions, so drive 1 for Condition 1 was exactly the same as drive 1 for the other conditions. Drive 2 for Condition 1 was exactly the same as drive 2 for the other conditions etcetera. The difference between the conditions was only present in the last drive that participants watched (drive 6). This last drive was different between conditions since the type of change that was shown was different from condition to condition. The first five drives were included to expose the participant to the original sign several times. This was done to increase pre-change awareness.

The idea of the different conditions was to assess the effect of different types of changes and of attention on glance duration and change detection. In the last drive, the critical traffic sign (warning for side street from the right as shown in Condition 1) was replaced in 4 out of 5 conditions (see Table 12.1).

Table 12.1 The 5 conditions in the experiment.

Condition	Traffic sign	
1		(no change)
2		
3		
4		
5		+ auditory warning

Condition 5 was similar to Condition 4, but just before 'passing' the critical sign an auditory warning was provided "Attention, traffic situation has changed". Participants were informed that this message would be played just before presenting the change. This message was played in order to increase attention.

One of the hypotheses was that with a larger difference between the changed sign and the original sign, the level of Change Blindness decreases. In order to study this, the difference between the signs needs to be quantified. Quantifying the difference was done by dividing the number of pixels that were the same in both signs by the total number of pixels in the sign. This was done for the black and the white image; the red triangle was not included in this calculation. When the different traffic signs were compared, there was a 5% difference between Condition 2 and 1, a 32% difference between Condition 3 and 1, and a 44% difference between Condition 4 (and 5) and Condition 1. There is however also a second measure of the type of change introduced and this is how well a sign fits the scene. This was calculated by showing the traffic signs in the scene (pictures as shown in Figure 12.6 to 12.9) and having 20 naïve participants rate how well they though the sign fit that scene on a scale from 1 (does not fit the scene at all) to 10 (perfectly fits the scene). This led to an average score of 8.9 for Condition 1 (the original sign, side street from the right), a 1.2 for Condition 2 (side street from the left), 6.2 for Condition 3 (playing children) and 1.7 for Condition 4 (running off a quay). Therefore we can say that for Condition 2 and 4, the changed sign fit the scene less than in Condition 3.

Again, Condition 1 was the control condition in which the original traffic sign (side street from the right) was not changed in the last drive. So participants were asked for a change whereas there was no change present. In Condition 2, there was only a small change (5%) in the image that was shown on the traffic sign, with the 'warning for a side street from the right' being changed in a 'warning for a side street from the left'. On the other hand, the sign did not fit the scene since there was no side street on the left side. In Condition 3, the original traffic sign changed into a traffic sign 'warning for playing children'. Even though the physical change was larger (32%) compared to the 'side street from the left' sign (Condition 2 (5%)), it was a sign that would fit the residential area that was shown in the videos. In Condition 4, there was a relatively large change (44%), since here the traffic sign now showed a 'warning for running off a quay', which was a traffic sign that did not very well fit the scene. Condition 5 was similar to Condition 4 ('warning for running off a quay'), but only here an auditory pre-warning was given. About 200m before passing the changed traffic sign, a voice message said: "Attention, traffic situation has changed". This was supposed to increase the attention level. Participants in this condition knew that they would receive this warning just before the change, but just like the other participants,

they were also told to pay attention in all drives in order to be able to detect what had been changed. An earlier driving simulator study (Martens, 2005) showed that an auditory warning for a change improved drivers' response to a sudden change in a traffic situation (indicated by a changed traffic sign) if drivers were not previously told that there would be a change.

Examples of the original sign and the changed sign that were presented in the scene are shown in Figure 12.6 to 12.9. The figures show the scene that participants watched just before the video was stopped and blacked out.

Figure 12.6 The original scene (warning for a 'side street from the right'). This sign was also shown in the last drive of Condition 1, since this was the control condition without any change.

Figure 12.7 The scene shown in the last drive of Condition 2 (warning for a 'side street from the left').

Figure 12.8 The scene shown in the last drive of Condition 3 (warning for 'playing children').

Figure 12.9 The scene shown in the last drive of Condition 4 and 5 (warning for 'running off a quay'). In Condition 5, participants also received an auditory warning that the change would appear.

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11.2.5 Apparatus

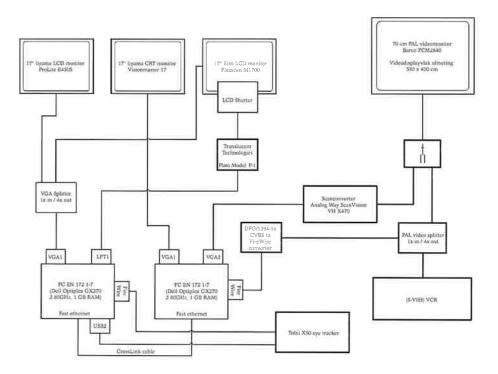The apparatus used in the experiment is schematically represented in Figure 12.10.

Figure 12.10 The apparatus used in the experiment, representing the computers, the Tobii eye movement equipment, the television monitor, the video recorder playing the video, computer monitors and the LCD shutter.

As was already mentioned, the Tobii X50 eye tracker was used for measuring gaze direction. All details about the equipment can be found in Figure 12.10.

12.2.6 Statistical analyses of glances

Glance duration was calculated for traffic signs by means of automatic tracking of the Tobii system. In case of multiple glances to the same object, glance durations were summed. For the current experiment, it was important to measure whether participants actually glanced at the changed traffic sign and, if they did, whether this glance duration was longer compared to a traffic sign that did not change. In order to have a reference value, glance duration to three other traffic signs (traffic sign 1, 2 and 4 as presented in Figure 12.2) was also measured.

Total glance duration was measured in msec. Glance duration was analysed by means of various ANOVAs (analysis of variance), using Condition (with 5 levels), Drive (with 6 levels) and Traffic sign (with 4 levels) as independent variables.

Other dependent variables are Change Blind or Change Aware and correct or incorrect identification of the traffic signs in the traffic sign identification test.

For all statistical tests, differences were considered significant if $p < 0.05$ and were marginally significant (trend) if $0.05 < p > 0.10$.

12.3 Results

12.3.1 Reported change

Participants' ability to detect a change in the traffic signs is presented in Table 12.2. There was only one occasion when a participant claimed to be Change Blind but reported to have seen the change after this was indicated by the experimenter. This response was treated as correct detection (Change Aware).

Table 12.2 The results of Change Detection for the four change conditions.

Condition		% correctly reported change
1		(original sign, no change)
2		11.5%
3		38.5%
4		50.0%
5	+ warning	65.4%

In Condition 1, the condition without the change, none of the observers reported a change. Table 12.2 shows that there was a relatively high incidence of Change Blindness in case of a change. Depending on the type of change that was presented, Change Awareness varied from 11.5% to 65.4%. This means that Change Blindness varied from 34.6% to 88.5%. As was predicted, there was a lower level of Change Blindness if the change to the original traffic sign was larger. There was an equal

decrease in Change Blindness with the increase in difference. The effect of the traffic sign not fitting the scene is less clear.

The number of Change Blind and Change Aware responses were compared using Chi-square tests. The results are shown in Table 12.3.

Table 12.3 Results of the Chi-square pairwise comparison between the number of correctly and incorrectly reported changes. n.s. is not significant.

Condition	2	3	4	5 + warning
2	-	$\chi^2 = 5.03$, $p < 0.03$	$\chi^2 = 9.03$, $p < 0.003$	$\chi^2 = 15.93$, $p < 0.0001$
3	$\chi^2 = 5.03$, $p < 0.03$	-	n.s.	$\chi^2 = 3.77$, $p < 0.05$
4	$\chi^2 = 9.03$, $p < 0.003$	n.s.	-	n.s
5	$\chi^2 = 15.93$, $p < 0.0001$	$\chi^2 = 3.77$, $p < 0.05$	n.s	-

All changes were statistically significant or marginally significant except for the difference between Condition 3 and 4 and between Condition 4 and 5.

12.3.2 Glance duration

By recording the x-y coordinates of the glance direction in time, it was possible to automatically analyse whether and how long participants were looking at traffic signs, as they were approached. Although many traffic signs were encountered during the route, glance duration was not analysed for all traffic signs.

Before data analysis, any sign of a difference in glance duration for traffic signs between the 5 conditions was assessed, since any difference in glance duration between the first five drives would have biased the Change Blindness results. There was no main effect of Condition on glance duration for traffic signs, suggesting that that in all conditions, glance duration to the four traffic signs along the route was comparable. There was a main effect of Drive [$F_{(4,504)} = 3.39$, $p < 0.01$], but a Tukey post-hoc test did not show any significant differences between the individual drives.

There was also a main effect of Traffic Sign [$F_{(3,378)} = 84.98$, $p < 0.0001$] if the four traffic signs that were shown along the route were included. Note that this analysis did not include any change, since here only the first five drives were included in this analysis. A Tukey post-hoc test showed that glance duration for traffic sign 1 (priority road) was lower than for traffic sign 2 (side streets from left and right) and 3 (side street from right) ($p < 0.001$ and $p < 0.05$ respectively), but higher than for traffic sign 4 (yield sign) ($p < 0.05$). Glance duration for traffic sign 2 and 3 were higher than for traffic sign 4 ($p < 0.001$ in both cases).

Glances towards the changed traffic sign in the last drive were first assessed for all participants, regardless of glance duration. This was then compared to their level of Change Blindness. This led to four different behavioural categories. These results are presented in Table 12.4. Condition 1 is not included here since there was no change in traffic signs.

Table 12.4 The percentage (and absolute number) of participants for four different behavioural categories.

Condition	1	2	3	4	5
					+ warning
No glance and change blind		30.8% (8)	16.0% (4)	37.0% (10)	34.6% (9)
Glance and change blind		57.7% (15)	48.0% (12)	14.8% (4)	0.0% (0)
Glance and change aware		11.5% (3)	36.0% (9)	48.2% (13)	65.4% (17)
No glance and change aware		–	–	–	–
Total		100% (26)	100% (25)	100% (27)	100% (26)

If participants failed to glance at the traffic signs, they also failed to report the change. However, the difference in percentage of Change Blindness between conditions cannot be explained by having a higher percentage of participants not taking a glance at the critical traffic sign. Condition 2 in which the sign 'side street from the right' changed into 'side street from the left' had the highest percentage of Change Blindness, but it also had the highest percentage of people glancing at the critical traffic sign. Therefore, the difference in Change Blindness between the different conditions can only be explained by having different Change Blindness levels in the participants who actually did take a glance.

Table 12.5 provides the numbers and percentage of participants that were Change Blind when only those participants that glanced at the critical traffic sign were included. Here it is interesting to see that there seems to be a gradual decrease in Change Blindness with an increasing difference with the original sign, but there is a disproportionately large decrease for Condition 4, the 'warning for running off a quay'. This may have been because the sign did not fit the driving scene. This issue will be discussed further in paragraph 12.4.

It may have been that there were differences in glance durations to the critical traffic sign between the conditions. The results are indicated in Table 12.6.

Table 12.5 The percentage (and absolute number) of participants that were Change Blind when only taking participants into account that glanced at the critical traffic sign.

Condition	1	2	3	4	5 + warning
Glance and change blind	83.3% (15)	57.1% (12)	23.5% (4)	0% (0)	
Glance and change aware	16.7% (3)	42.9% (9)	76.5% (13)	100% (17)	
Total	100% (18)	100% (21)	100% (17)	100% (17)	

Table 12.6 The glance durations to the critical sign for the four different behavioural categories (measured in msec).

Condition	1	2	3	4	5 (+ warning)	total
No glance and change blind		0	0	0	0	0
Glance and change blind		740	861	955	–	815
Glance and change aware		1860	1787	1758	1836	1803
No glance and change aware		–	–	–	–	–

This table indicates that for the 'glance and change aware' category, there was no difference in glance duration between the different conditions. However, there was a difference in glance duration between the Change Blind and the Change Aware, with longer glances for the Change Aware condition.

As a next step, glance duration was analysed including a new variable: Change Blindness, with 2 levels, Change Blind and Change Aware. In this analysis, Condition 1 (control condition with the original sign 'side street from the right') was not included since it did not contain a change. However, the glance duration for this control condition is plotted in Figure 12.11. Results showed a main effect of Change Blindness on glance duration [$F(1,96) = 49.78$, $p < 0.0001$], with higher glance duration for those participants who detected the change (1803 msec versus 407 msec). There was also a 2-way interaction between Change Blindness and Drive [$F(5,480) = 7.61$, $p < 0.0001$], shown in Figure 2.11. This interaction showed that the difference in glance duration was even larger in case of the actual change (drive 6).
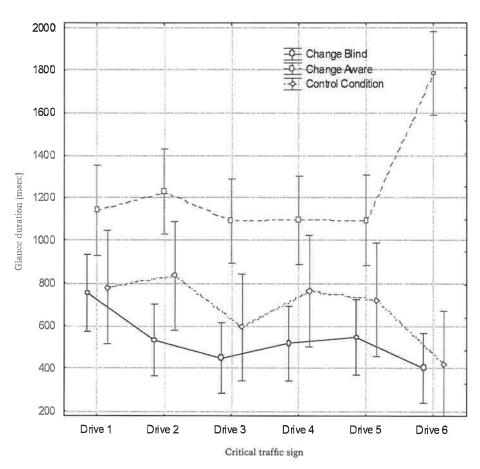
Figure 12.11 Average glance duration for Change Blind participants, Change Aware participants and the control condition. The bars indicate the standard error.

There was no interaction between Change Blindness, Condition and Drive, indicating that this pattern was similar for all conditions, so there was no difference in glance duration to the changed sign between the different conditions. This means that the difference in Change Blindness between conditions cannot be explained by shorter glance duration per se in conditions with higher Change Blindness levels.

12.3.3 Traffic sign identification test

Altogether, participants had to identify 10 traffic signs that were briefly presented on a computer monitor, according to their own personal threshold time. Table 12.7 shows the results, indicating the percentage of correctly identified traffic signs. Percentages printed in bold indicate that participants were actually confronted with that traffic sign in the video, possibly leading to higher percentages of correct

identification. The idea here was to focus on traffic sign 8 ('running off a quay'), 9 ('playing children') and 10 ('side street from the left') since they were presented in some conditions and not in others. Traffic sign 8, 9 and 10 therefore offered the possibility to reveal implicit traffic sign perception since prior presentation may lead to better identification in this task.

Table 12.7 Correct answers to the traffic sign identification test per condition.

Condition		1	2	3	4	5
1		48%	59%	73%	48%	74%
2		78%	63%	62%	74%	67%
3		96%	92%	96%	100%	100%
4		59%	44%	38%	30%	48%
5		78%	67%	81%	70%	74%
6		30%	44%	35%	33%	26%
7		67%	78%	73%	89%	59%
8		33%	26%	35%	30%	44%
9		81%	96%	92%	85%	89%
10		63%	52%	46%	63%	63%

What is clearly shown in Table 12.7 is that the expected effect of implicit information processing was not found. There was no better identification for those participants that were confronted with the traffic sign in comparison to participants that had not been confronted with the sign. Better identification was expected of traffic sign 8 ('running off a quay') for Condition 4 ('side street from the right' changed into 'running off a quay') and 5 ('side street from the right' changed into 'running off a quay' + auditory warning) compared to Condition 2 ('side street from the right' changed into 'side street from the left') and 3 ('side street from the right' changed into 'playing children'). This did not turn out to be the case. There was also no better identification of traffic sign 9 ('playing children') for Condition 3 ('side street from the right' changed into 'playing children') compared to the other conditions, nor of traffic sign 10 ('side street from the left') for Condition 2 ('side street from the right' changed into 'side street from the left') compared to the other conditions. Also, making a distinction between the Change Blind and the Change Aware did not lead to better results on this test for the Change Aware. Apparently participants' ability to identify the briefly presented traffic signs did not depend whether they were previously confronted with the traffic sign. Even explicit detection (for the participants that detected the change) did not help to identify the traffic sign in this traffic sign identification test.

12.4 Conclusions and discussion

In the current experiment, many instances of Change Blindness were found, despite the fact that the changes were task related. This means that Change Blindness is not the mere result of the changes not being detected because they are not relevant for the task at hand. This corresponds to earlier results of a driving related study by Martens and Fox (in press) that showed that participants failed to respond to an unexpected change in priority, even though this change was highly task related. However in that study, participants were not specifically instructed that a change would be present.

In the current study, Change Blindness clearly depended on the type of change that was presented. There was a linear decrease of Change Blindness with an increasing difference between the original and the changed sign. This means that the explicit detection of a change depends on the amount of difference between the original and the changed information. A small change only led to 11.5% detection, whereas a bigger change resulted in 38.5% or even 50% detection. However, even though Change Detection was statistically higher in case of the larger change, Change Blindness was still 50%. This low change detection rate cannot simply be explained by people generally not paying attention, since one of the conditions actually raised

the attention level just before the change, since it was accompanied by an auditory message 'Attention, traffic situation has changed' (and informing participants that this message would be played just before presenting the change). Detection was somewhat larger than without this message, but it did not reach statistical significance compared to the same change without the warning. This low number can also be explained by some participants not glancing at the change. In contrast to the results of O'Regan, Deubel, Clark and Rensink (2000), who found some cases of Change Detection without any glances directly at the changed item, this was not found in this experiment. There were no instances of change detection without a glance directly at the sign. This difference may be explained by the fact that O'Regan and his colleagues used static scenes instead of dynamic scenes. In static scenes, information in the visual periphery does not change location if an item is fixated whereas this is the case in a dynamic scene. Therefore it is more difficult in our experiment to identify visual information in the periphery since both the fixated item and the item in the visual periphery continuously move. For participants that glanced at the critical sign, Change Blindness is much lower.

The current experiment showed that when only those participants are taken into account that glanced at the sign, there is no linear decrease of Change Blindness with an increasing difference. For the traffic sign that changed most and did not fit the scene, Change Blindness was less than was expected on the basis of the difference alone. Here it may very well be that the fact that the traffic sign did not fit the scene may have increased change detection. The traffic sign that changed the least compared to the original sign did not profit from this 'not fitting the scene'. In this case, it may be that the difference with the original sign was so small that the difference between the original sign and the traffic sign not fitting the scene was not even noticed. It is very likely that there has to be a sufficiently large difference between the original information and the changed information before 'not fitting the scene' will actually lead to improved change detection. Only in case of a bigger change that did not fit the scene with the auditory message raising attention, Change Blindness was 0% for all participants that glanced at the critical sign.

A second interesting finding was that there was a significant difference in glance duration between participants that explicitly perceived the critical traffic sign and those who took a glance but did not report seeing the sign. This difference in glance duration between the Change Blind and the Change Aware was already present before any changes were presented yet. This shows that the long glance duration for the Change Aware participants was not a consequence of explicitly perceiving the change but rather the reason that they perceived the change in the first place.
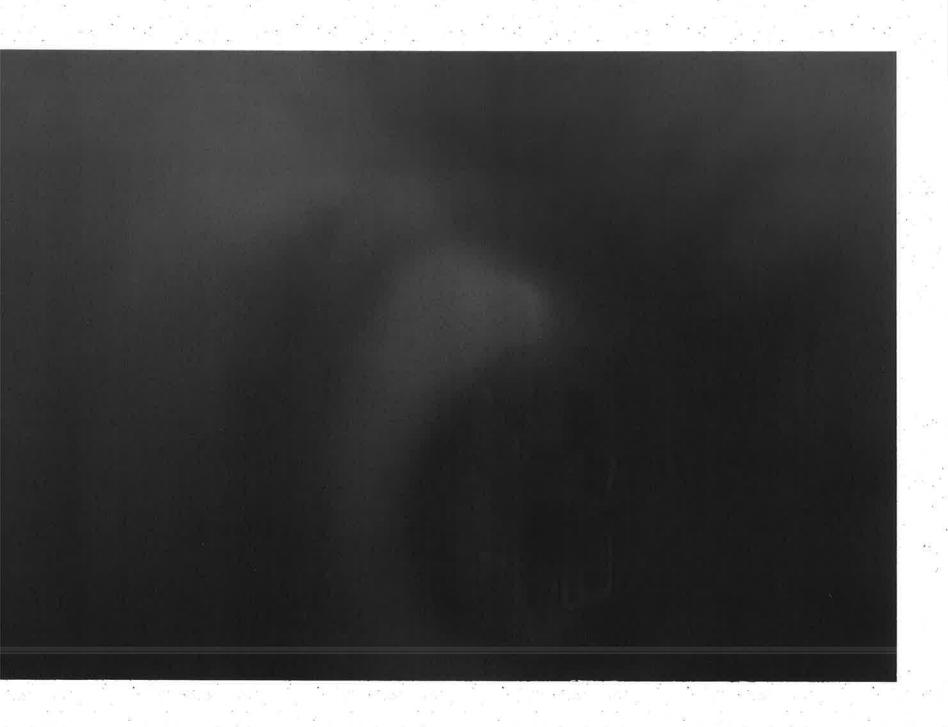
This suggests that there is a value for minimal glance duration in order to allow explicit processing. Glance durations that are below this limit do not result in explicit perception. Unfortunately, when looking at the individual glance duration data, there was no absolute minimal glance duration that guaranteed explicit perception. There was an overlap between the glance duration data of the Change Blind and the Change Aware, which means that there was not a strict criterion which allows a perfect prediction of whether participants will explicitly notice the change. But the data clearly show that participants with higher glance durations at traffic signs are more likely to explicitly perceive the change. And when the change is detected, glance duration increases even more.

In contrast to what was found in earlier studies (Martens & Fox, in press; Martens & Fox, 2007), there was no general decrease in glance duration at traffic signs over the drives. The absence of this decrease in glance duration in contrast to the earlier studies is most likely the result of the instructions provided to participants in the current study. Participants were instructed to pay attention to traffic related items and they knew they had to detect a change that they could only detect if they paid attention from drive to drive. However, despite the current instruction, about 30% of the participants did not glance at the critical traffic sign. If glancing at a sign is a minimal requirement for perception, pointing to the visual selection of that particular information, than this explains about 30% of the Change Blindness cases. Change Blindness can also result from participants detecting the change but not realising that this is the change that is meant. In this experiment, participants were explained in the end what the change had been, offering them the possibility to indicate that they indeed perceived that sign without having realised that it had changed. This only happened once in all 131 cases. This means that in almost all cases, participants immediately detected the change at the moment they passed the changed sign or they did not at all.

In the current experiment, there are no indications that the Change Blind have implicitly processed the information. The traffic sign identification test did not show better performance for those who were confronted with specific traffic signs in comparison to those who had not. The problem here may be that the test is not sensitive enough. Even the Change Aware did not show better performance compared to participants who were not previously confronted with the traffic sign. However, there are also no indications of implicit processing of the information for the Change Blind in terms of glance duration. We did not find higher glance durations in case of changes for the Change Blind. In case of the change, glance duration for the Change Blind was even somewhat shorter than glance duration for this specific sign on earlier drives.

In conclusion, there are various factors that play a role in Change Detection. A first factor that plays a role in explicit perception is selecting the relevant information as evidenced by a glance at the critical sign. A second factor seems to be the duration of the glance. This is shown by the fact that people who initially have longer glances at all traffic signs had a higher chance of Change Detection. An additional finding is that in case of the explicit perception, the change so to say 'grabs' the glance for a longer period of time, leading to higher glance durations in case of changes compared to no changes. So the higher initial glance duration allows deeper processing, leading to Change Detection (glance duration as a cause), with Change Detection increasing glance duration even more if it enters awareness (glance duration as a consequence). And a third factor that seems to play a role is the type of change. The larger the difference between the original and the changed information, the higher the chance of change detection. If the difference is large enough, the fact that the presented information does not fit the scene seems to also improve change detection. Actively raising the level of attention at the moment of the change improves Change Detection for those who glance at the traffic sign.

In traffic environments, experienced drivers have strong expectations about the presence of traffic signs or priority situations. Sometimes these expectations are based on prior experience of driving the road, sometimes these expectations are based on the way the road is designed (a.o. Martens, 2005; Theeuwes, 1996; Kaptein & Theeuwes, 1996; Martens & Fox, in press). This means that there is a risk in changing traffic related items that are not in accordance with the expectations of the driver (a.o. Martens & Fox, in press; Martens, 2005). Although a first aim of a road designer should be to design according to driver expectations, it may be necessary to change a road situation. In this case, the changed situation will not meet the expectations of drivers that have been driving the road for a long time. In order to improve explicit perception, various combined measures need to be taken. One basic measure is to attract glances in order to guarantee selection. The second measure is to affect glance duration, ensuring longer glances. This allows the selected information to be processed to a deeper extent. The third measure is to make the difference with the previously shown information as large as possible, in order to come to explicit detection. Based on the current findings, we claim that the larger the difference between the original item and the changed one, the higher the chance of breaking through their expectations, leading to explicit perception. With respect to driving, this means that when changing a traffic situation, there is a risk that the change will not be detected. Therefore, the cues indicating the new situation would need to be clearly distinct from the former situation. Simply replacing one traffic sign with another is not sufficient. Using various cues could help selection of at least one cue, increasing the chance of detection of that cue, thereby raising attention and increasing the chance of detection of other cues.

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Discussion and conclusions

The phenomenon, central to this thesis is 'the failure to apprehend'. The phenomenon describes the situation in which information is clearly visible in a scene, but the observer does not act upon the presented information even though the information is relevant for the task.

The thesis started by discussing literature that is related to this phenomenon. In Change Blindness and Inattentional Blindness studies, numerous examples are available of observers not acting upon apparently clearly visible information. This may be the result of either a failure to select the information or a failure to respond. If information is not selected (for instance someone does not glance at the information), it cannot generate a response. However, even in case of selection, it is possible that the selected information is not sufficiently processed to generate a response.

After assessing the type of situations in which 'the failure to apprehend' occurs (e.g. high task load or in case of expectations), an elaborated task performance model was introduced. This elaborated task model was mainly introduced as a framework to explain 'the failure to apprehend' in driving and to link the concept of expectations to Rasmussen's task performance model. Rasmussen's model is elaborated by introducing the main factors of top-down and bottom-up control. Also, factors that are influenced by the various task levels, such as attention, arousal, task load and required time are included.

This thesis focuses on the mid level of the elaborated task performance model. This mid level is called rule-based behaviour, with a link to schemata and expectations. In the remaining chapter, we discuss the results of the studies in the light of this model and discuss what can be done to avoid 'the failure to apprehend' at this task level.

13.1 Top-down versus bottom-up in normal conditions

One of the assumptions of the model is that knowledge-based tasks (or new tasks) are characterised by bottom-up processing and lack of top-down control. Even though this thesis did not focus on this task level, the lab tasks in this thesis were initially performed at a knowledge-based performance level. None of the participants had any experience with this task. However, by allowing half of the participants to develop expectations about the occurrence of targets, we manipulated the level at which the task presumably was performed. We expected that by training half of the participants with this task, their performance would be executed at a rule-based or schemata level.

With knowledge-based performance, glance duration to all stimuli was equal. However, expectations (schemata-based performance) changed the way that people scanned their environment. Expectations introduced top-down control, illustrated

by a change in glances to the presented stimuli. In case of expectations, people spend more time glancing at information they expect to be relevant for the task. Even though the bottom-up features at both task performance levels were exactly the same, it was top-down control that determined how long people glanced at specific items.

But how does this relate to real world tasks such as driving? Since we used experienced car drivers as participants, and people did not have to find their route, people did not perform all aspects of the task at a knowledge-based level. However, we could still manipulate expectations, as we did in the lab tasks, by having road users drive the same road several times. This manipulation did affect expectations as shown by the observation that after several drives, road users had stronger expectations about what information was presented at what location. That this also introduced top-down control was shown by the observation that also in this task, expectations changed drivers' scanning strategy. With increased familiarity with the road, drivers spent less time glancing at traffic signs. Again, the bottom-up features remained the same (since the traffic signs are the same from drive to drive), but glance duration decreased, showing the effect of top-down control.

Together the results of the lab and the driving tasks show that with stronger expectations, less active information processing takes place. Glance duration to irrelevant information decreases (lab tests), but also in case of relevant information (e.g. traffic signs in the driving tasks), familiarity with a road decreases glance duration. This shows the difference between bottom-up and top-down control.

13.2 Top-down versus bottom-up in case of incorrect expectations

The elaborated task performance model assumes that in case of rule-based performance, top-down control is so strong that there is not much room for bottom-up features. This strong top-down control may lead to 'the failure to apprehend'.

In order to study the strength of expectations and top-down control, we introduced a change in the tasks. In those cases in which the presented information was not similar to what was previously presented, or so to say did not correspond with the expectations, 'the failure to apprehend' was found. Apparently the top-down control was indeed so strong that the bottom-up features were not strong enough to overcome this. Given the model that we outlined, this was exactly what was expected. Even though in many cases, the changed information was selected, with people actually looking at the information, the response often corresponded to the old situation rather than to the newly presented information. In many cases, there was no response at all and even if there was a response, response times were long or

the response was not strong enough. In case of the driving task, there were instances in which the new sign indeed seemed to affect driving speed, but only to a rather small extent. An interesting phenomenon in this is that 'the failure to apprehend' also occurred in situations without familiarity with the road. In these cases drivers drove the road for the first time. This shows that top-down control is not only linked to familiarity with the road, but also to the design of the road in itself. Apparently, experience with various roads in the past has also generated schemata of what to expect in similar road environments. These schemata have a similarly strong top-down component as being familiar with one specific type of road.

In a Change Blindness task, one cannot really speak about incorrect expectations in case of a change. People were instructed that there would be a change, which probably kept the arousal and attention level at a relatively high level. The main result was that people who noticed the change had longer glances at the traffic sign in all 'drives' (even in drives without any change) than people who did not notice the change. This shows the close link between glance duration and level of processing. Longer glances allow deeper processing and therefore resulted in less occurrence of 'the failure to apprehend'. In case of the actual change, glance duration was even longer for those who noticed.

Together these results show that when a change or unexpected information is presented, the new information is often not selected or selected but insufficiently processed. In these cases, responses are absent or inadequate (e.g. slow response). 'The failure to apprehend' in driving is also present without familiarity with the specific road. This shows that expectations do not always have to be the result of experience or familiarity with that exact road. A road may also elicit expectations by the way it is designed, with strong top-down control even if the road has not been driven before. The longer the glance at the changed information, the higher the chance of a response.

13.3 Top-down versus bottom-up: the balance

The elaborated task model describes 'the failure to apprehend' at all task levels as the result of the inbalance between top-down and bottom-up selection and processing. In case of expectations or schemata – i.e., at the rule-based level – , the top-down influence is so strong that there is not much room for bottom-up features. At this level, 'the failure to apprehend' is the result of this too strong top-down control in case of incorrect expectations.

In order to avoid 'the failure to apprehend' under those circumstances, there are three possible approaches.

The first approach is to only design roads that perfectly match driver expectations and fit the schemata. An attempt to do this has been the Dutch road design concept of Sustainable Safety. The concept of Sustainable Safety was introduced in order to decrease the number of injuries and fatalities in road traffic in the Netherlands. The idea is that all roads should be designed in such a way that road users know what type of behaviour is expected of them (in terms of speed, having priority, overtaking etc.) and what type of other users they will encounter (cars, cyclists, mopeds and slow agricultural vehicles etc.) just by looking at the road. Sustainable Safety acknowledges that this self-expaining character of roads can only be realised if there is a limited number of road categories and if they are designed according to specific rules. This means that within one road category, design characteristics have to be similar and between road categories they need to be different. Although in itself, the idea is excellent (since it allows road users to develop schemata that are linked to specific road categories) the problem is its implementation. The implementation of Sustainable Safety in the Netherlands is decentralised. This means that different local road authorities are responsible for implementing Sustainable Safety in their own region. Since the implementation also has to fit the local budget, there still may be quite some variation within one road category. Also, several examples are shown in which road authorities do not implement the right design characteristics for the road category. For instance, there are already examples in the Netherlands in which a characteristic that belongs to the design characteristics of road category A is used in case of road category B. This real-life example shows that it is not so easy to perfectly harmonise road categories throughout an entire country, let alone harmonise them over country borders.

A second approach would be the opposite: Avoiding any top-down control by preventing any driver expectations, thereby avoiding schemata. The problem with this approach is twofold. On the one hand, it requires a rather complicated co-ordination between road authorities. This co-ordination is even more difficult than the co-ordination required for implementing Sustainable Safety. In order to avoid the development of schemata, there should be quite large differences and variation between roads of the same category. Only by making the design within one type of road very different from one road to the other, expectations and schemata will not develop. This is a very complicated design process and the risk of developing schemata and expectations is still there if drivers get familiar with a specific road. The second problem is that this would bring the driving task back to the task level of a novice driver, that is, to the knowledge-based or new task level. This poses a rather high task load and there are many visual elements competing for selection. This may also result in 'the failure to apprehend', even though here it is caused by too strong bottom-up control. The advantage of top-down control is completely lost, with an increase in workload. Since novice drivers are known to have a high accident
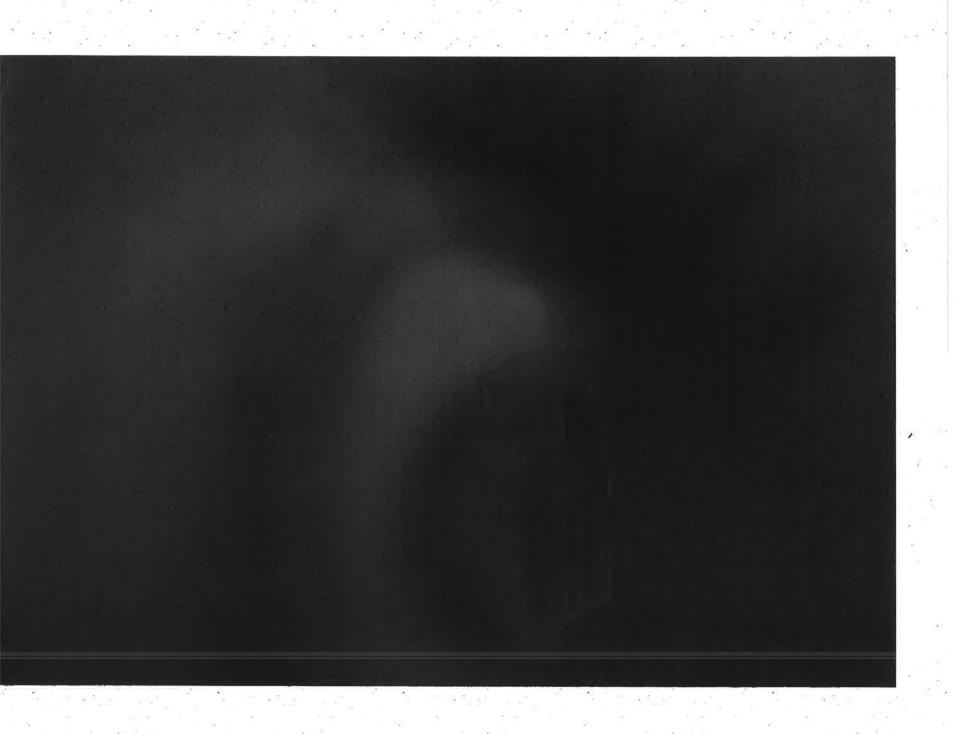
risk, probably due to this high workload, the fact that many more visual elements compete for selection, and that they are not able to handle complex situations since they have to rely on bottom-up processing, one may question if this approach really improves safety.
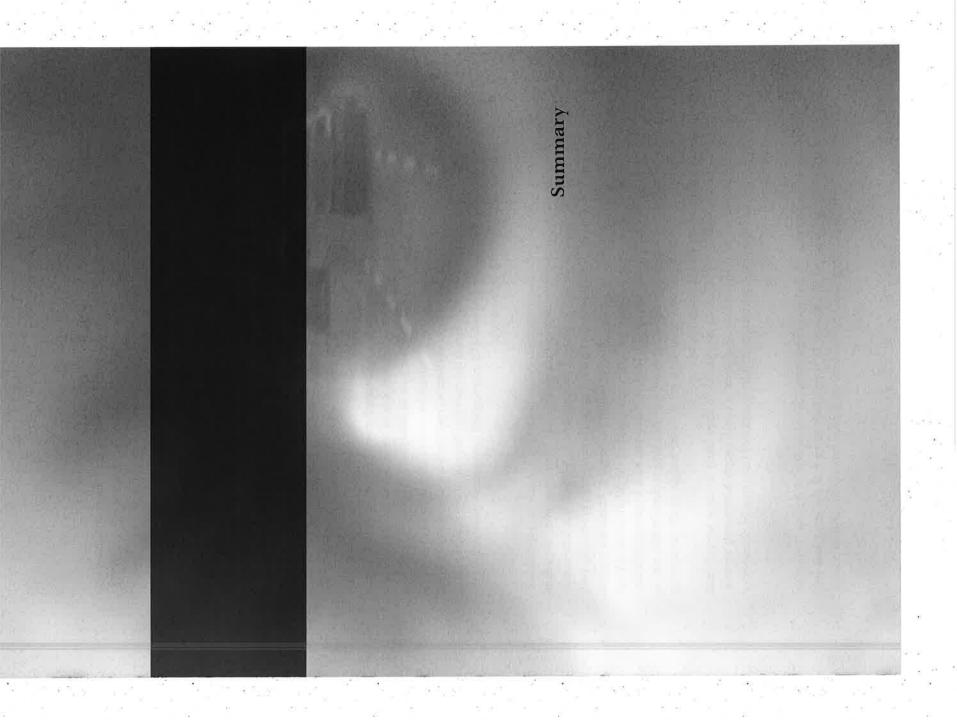
The third approach is to increase the strength of the bottom-up features of new or unexpected information in order to get more balance between top-down and bottom-up. By strengthening bottom-up features, a balance may be found without losing the advantages of top-down control. As previously discussed, a first requirement for a response is the selection of the relevant information. Although it is possible to attract the gaze by means of highly conspicuous items such as a flashing light, this is not the proper way to proceed. We want to avoid creating a road environment with many flashing lights to attract attention, since this will decrease the attentional value in general if they are used very often. Also, they imminently warn all drivers whereas the warning is not necessarily relevant for all drivers. Moreover, they may attract attention away from other imminent items such as the activation of braking lights of the car in front or a child that crosses the street. Therefore, it seems more appropriate to suggest another measure. What we can learn from the experiments is that in case of an auditory warning, there were no cases of 'the failure to apprehend' in driving. The most likely assumption is that the auditory warning changed drivers' scanning behaviour to a more active one. This most probably resulted in more drivers selecting the new traffic sign and taking longer glances than without this message, bringing task performance more towards a knowledge-based level of a novice driver. However, we have to keep in mind that in knowledge-based or new tasks, there is much competition between presented elements in the environment. A disadvantage of a warning – bringing the task performance to a bottom-up level of processing – could therefore be that a driver selects as many items from the visual surroundings as possible, whereas the purpose of the warning is that the driver selects the specific critical item. Therefore, an auditory warning is only effective if it leads to the selection of the right information, and not just of any information. In order to make sure that the relevant information is selected if the auditory message is provided, there should not be other items competing for selection. It is therefore important to limit the amount of other signs and signals. This also accounts for other conspicuous visual elements in the vicinity of the changed or deviant situation. Limiting the amount of visual information increases the chance of selecting the right items. But how will this auditory message be implemented? In a future scenario, a driver always carries a personal driver card. This card contains all sorts of personalised information such as the preferred position of the mirrors and the chair, the favorite radio station and information about where the road user has been driving and what road situations have been changed since the last time he or she drove there. This personal card will be inserted into the car at each drive and will activate a system that warns the driver for a changed traffic situation or for black spots where

accidents often occur. The big advantage of these systems is that they are personal, so they will only be activated if drivers previously encountered a different situation. This has advantages to flashing lights that will also warn drivers that drive the route for the first time.

Now, if the item is selected, a second requirement for a response is sufficiently deep processing. This can be done by making the difference with the former or the expected situation as large as possible. The larger the difference between the changed situation and the original one, the higher the chance of a response. The difference can be the location of a sign (not replacing the old sign with a new sign but also changing its location), the form of the sign (triangle, square, round), the colour of the sign, the size of the sign (enlarging it), the type of sign (warning sign, information sign, etc) and most importantly the pictogram or text shown on the sign. Also, additional measures have to be taken to increase the strength of bottom-up control, like road markings (timely in order to allow the information to be processed) and additional traffic signs. This does not only hold for road situations that are changed, but also holds for situations in which there is an exception compared to similar roads. An example in this case may be that there is a side road that has priority whereas other similar side roads do not have priority. The more different the road design is compared to previous designs, the stronger the bottom-up features and the higher the chance of the proper response. The effectivity of this approach is directly derived from this thesis. Very subtle implicit additional cues do not have any effects, bottom-up features really have to be strong.

The idea that information with strong bottom-up features that is not in line with expectations will lead to selection and deep processing is exactly what is used to attract attention to advertisements along the road. The purpose of the advertisement agency is to attract as many and as long glances as possible. The purpose of the road authorities is that advertisements attract as little and as short glances as possible. Therefore, the question is what type of advertisements are too distracting for the driving task and what type of advertisement can still be allowed by the road authorities. Based on this thesis, we claim that only for advertisements that present a very limited number of items (e.g. one short word together with one slogan or one pictogram or logo) and present items that are well-known (for instance a well-known logo or a non-ambiguous picture), glances will be sufficiently short to not adversely affect road safety. Advertisements that are very large, are dynamic, flash, present several items, have long text, are ambiguous or show logos or symbols or pictures that need more than some seconds to be fully processed need to be forbidden along the side of the road. This is also the case for information shown on advertisements that have a large subjective relevance, such as advertisements showing people in their underwear or shocking images like the results of road accidents. These advertisements should not be allowed along the side of the road.

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Summary

Responding to relevant visual information is of crucial importance in almost any task. This thesis studies the mechanisms that underlie 'the failure to apprehend'; the phenomenon of not acting upon clearly visible and relevant information.

Chapter 1 through 6 describe the literature in the field and provide a theoretical framework for the thesis. Chapter 7 through 12 describe the experimental work that has been done. Chapter 13 ends this thesis with the discussion and conclusions.

Chapter 1 describes the 'failure to apprehend' in the context of Inattentional Blindness and Change Blindness. Inattentional Blindness refers to the phenomenon that people do not notice unattended objects or events, even though they may be relevant for their task. In case of Change Blindness, observers are not aware of a change that took place, even though the change is clearly visible.
In order to respond to information, it needs to be processed first. In order for information to enter the information processing cycle, it needs to be selected from all available information. 'The failure to apprehend' may be the result of information not being selected. **Chapter 2** describes this role of visual selection in the ability to respond to information. An important role in selection is played by attention. Attention is the mechanism that selects stimuli for further (higher-level) processing. Under normal conditions, with people performing real life tasks, selection takes place overtly by directing the eye to the visual information. The role of eye movements in information processing is explained, with a strong link between attention and glance direction in natural task performance.

Chapter 3 provides evidence that there may also be cases of 'the failure to apprehend' even though the appropriate information is selected. There may even be indications that the information was processed to some extent, without the information leading to a response. This may be the result of not sufficiently deep processing, with insufficient cues to lead to a response or a failure in memory. Therefore, explicit performance measures (e.g. asking whether people noticed the information) are not always the best performance measures. Implicit measures, such as glance duration, response times or the possibility to implicitly use this information for the task at hand should also be taken into account to get a better insight in the underlying mechanisms of 'the failure to apprehend'.
Situations in which 'the failure to apprehend' is most likely to occur are provided in **Chapter 4**. These situations are conditions in which people have strong expectations, show automated task performance, have a vigilance tasks type of character or induce a high workload.

Chapter 5 discusses the 'failure to apprehend' in the context of driving. To explain the underlying causes of 'the failure to apprehend' at each of the three task performance levels of Rasmussen, we propose an elaboration of his original model.

The elaborated model links automated task performance to skill-based behaviour, with a low level of arousal, attention, and task load. It requires little time to perform and the task is normally well-practised. The problem with this task level is that there is hardly any room for top-down control. Rule-based behaviour is linked to expectations and activated schemata, with an intermediate level of attention, arousal and workload. It requires more time to perform the task and it is less practised than tasks at the skill-based level. This level of performance is characterised by a strong top-down control, leaving little room for bottom-up features. The knowledge-based level is linked to new tasks, with a high level of attention, arousal and workload. Performing the task requires relatively much time and the task is hardly practised. Information processing takes place in a bottom-up manner, with almost no top-down control. Even though 'the failure to apprehend' may take place at any of these levels, the causes may occur at different levels. At the new task level, 'the failure to apprehend' is most likely the result of the failure to select the right information at the right time because of a limited processing capacity and no top-down control, resulting in competition between all displayed items. At the schemata level, 'the failure to apprehend' is the result of too strong top-down control; top-down control that is so strong that it does not allow the bottom-up input of signals that do not fit the top-down schemata. In case of automated behaviour, 'the failure to apprehend' is also explained by the lack of top-down control; the presentation of an item automatically triggers the response, even if in this case it is not the correct response.

Chapter 6 addresses the focus of this thesis. It explains the difference between the driving task and some classic Change Blindness and Inattentional Blindness tasks. In most Change Blindness and Inattentional Blindness tasks, participants are instructed what to attend to or what to search for, whereas this is not the case in normal driving. Also, the information of interest is not always relevant for the observer, whereas this thesis focuses on task relevant items. A third difference with Change Blindness tasks is that they specifically focus on detecting the change, whether our main focus is on responding to information that is currently there (irrespective of whether it was different before). The main research questions of this thesis are: What is the effect of developing expectations on eye movement behaviour and the occurrence of 'the failure to apprehend', what type of information results in 'the failure to apprehend' and what type does not, and what type of information can help break through incorrect expectations, resulting in 'the failure to apprehend'? The main focus is the driving context.

Chapter 7 investigates the effects of expectations on eye glance duration and on 'the failure to apprehend' in two laboratory experiments. Glance duration and manual responses to predefined targets amongst distractors were measured in a dynamic and abstract environment shown on a computer monitor. Participants received a continuous flow of stimuli with either a predictable sequence of targets and

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distractors or with a random sequence. In the predictable sequence, participants were able to develop expectations about the order of targets and distractors. Under those conditions, glance duration for targets was longer than for distractors. In the random condition, participants were not able to develop expectations about the presentation of targets and distractors, which resulted in similar glance duration for targets and distractors. Responses to targets were much faster in the predictable than in the random condition. The problem with these expectations, that in normal cases decreased response times, was 'the failure to apprehend' in case of incorrect expectations. Information that did not meet the expectations was either missed (no response) or responses were extremely slow, substantially slower than in the random condition. These results clearly show the downside of having expectations and the strong impact of top-down control. The chapter concludes by stating that these results have major implications for all tasks that have strong top-down control over visual selection and information processing, like operator monitoring tasks or driving. In these types of task, the consequence of 'the failure to apprehend' and strongly delayed responses may be dramatic.

Chapter 8 assesses the effect of expectations on response time, response accuracy and glance duration, again in a lab type setting. In a dynamic and abstract computer simulated environment, participants responded to predefined targets amongst distractors that were again presented in a continuous flow. The character of the stimuli was different than that in the previous study decribed in Chapter 7. Infrequently, participants had to respond to targets that were not expected to appear at that moment or they had to refrain from responding when a target was not presented even though expected. Again we found that participants' glance duration to targets was longer than for distractors. Response times to unexpected targets were much longer than response times to expected ones. Many errors were made when unexpected information was presented, with most errors being made when a response needed to be inhibited. There was no difference in glance duration between participants with correct and those with incorrect responses in case of unexpected information. Interestingly, the presence of unexpected information did not change the glance strategy of observers. Again, these results show the strong negative impact that expectations and top-down control may have for real life tasks such as assembly line workers or air traffic controllers.

Chapter 9 investigates the effect of expectations on glance duration and responding to unexpected information in the driving context. Participants drove a low-cost simulator while their eye movements were recorded. In some conditions, participants got familiar with a particular road by driving this road several times during various days. The study showed that repeated exposure to the same road indeed increased familiarity with this road and it changed eye movement behaviour.

With repeated exposure participants spent less time glancing at traffic signs along the route while having a better recollection of the traffic signs along the route. When the road situation was changed (a priority road changed into a yield situation) without any specific instruction, drivers did glance at the sign indicating the new situation but did not process the information sufficiently to show an adequate response. Repeated exposure to the same road resulted in many inadequate responses to the change in priority, even though there was a new sign and there were priority road markings that were not present before. The current finding that incorrect expectations may cause drivers to miss important information even though they look at it is relevant to other monitoring tasks.

Chapter 10 assesses glance duration after multiple exposures to the same road in real driving conditions and when watching videos. Since it was already demonstrated that the duration of glances at traffic signs decreases in simulated environments, this study investigates whether this also holds in real driving and in a video condition. In the video condition, a video was taped during driving from the driver's point of view. While watching this video, participants had to pretend they were driving the car while simulating steering and braking. One of the main outcomes of the study was that the decrease in glance duration for traffic related objects with increased exposure that has been found in simulated environments was also found in real driving. A second important outcome is that this decrease has also been found in the video condition. This means that over all objects, the two methods lead to comparable results when investigating the duration of glances at objects. For glance frequency, people have slightly more glances at object when watching a video compared to real driving and the decrease with increased exposure is not as gradual as it is with glance duration.

The decrease in glance duration over days was quite comparable between watching a video and actual driving. However, there were also some differences in glance duration between the two conditions with respect to specific objects. This means that the video configuration is not useful for identifying objects that would receive longest and shortest glances under real driving conditions. Although there are objects that have long glances in the video condition that also have long glances in the real driving condition, there is no exclusive overlap. Therefore, great care is needed when using video instead of real driving to investigate glance durations and frequencies to traffic related objects. The video method is suitable for exploratory research, looking into glance duration at road objects and to assess the effect of multiple exposures or familiarity with the road environment on glance duration without being interested in exact glance duration in real life situations.

In **Chapter 11**, a driving simulator study is described that assesses the effects of familiarity with a road on 'the failure to apprehend'. The central question was

whether familiarity with the road results in 'the failure to apprehend' and whether
'the failure to apprehend' mainly occurs if drivers drive the same road several times
or whether it also occurs if the road environment partly varies from one drive to the
next. In order to study 'the failure to apprehend', a change to the road lay-out was
introduced from one drive to the next. In this study, a normal road was changed into
a No-Entry road. Participants were warned for this change in various ways, from just
putting up the No-Entry sign to additional signs warning for a change via auditory in-
vehicle messages. The driving simulator study showed that there was no difference
in the occurrence of 'the failure to apprehend' between the same drives and drives
that were varied. Even more so, 'the failure to apprehend' was not a consequence of
driving the same or a similar road numerous times, but rather the result of expecta-
tions that the drivers already had on the first drive. This indicates that there are situ-
ations in which 'the failure to apprehend' is not the mere result of prior exposure to
that particular road, but rather the result of the wrong expectations induced by the
road design itself. Even on the first drive, one did not expect the No-Entry situation,
leading to drivers entering this road. Adding information to point the driver to the
changed situation does decrease 'the failure to apprehend'. Although fewer errors
were made in case of an additional yellow sign indicating a change in the traffic
situation, there were still cases of 'the failure to apprehend'. Only by means of an
auditory in-vehicle message, there were no cases of 'the failure to apprehend'.

Chapter 12 used a Change Blindness task to assess 'the failure to apprehend' in a
driving related context. The purpose of the experiment was to study how large the
problem of Change Blindness actually is in case of task relevant changes. With task
relevant changes we refer to changes related to the task people are performing. In
this case, drivers were instructed to detect a change in a traffic related item, which in
this case was a change to a traffic sign. Another purpose was to study how the type of
change affects Change Blindness and to study the role of glance duration in Change
Blindness. The study was performed by having car drivers watch video films, taped
from the driver's point of view showing 6 drives around a block. Participants were
instructed to pay close attention to traffic related issues and to imagine they were
the driver of the car. They were also instructed that they had to look for a traffic
related change. Glance duration to traffic signs was measured as well as Change
Blindness (are participants able to explicitly detect the change). In drive 6, one of
the traffic signs was changed into a different traffic sign. There were five different
conditions, including one control condition without any change to the traffic sign.
In the four experimental conditions, the original sign was replaced by a different
official traffic sign. Implicit processing of the change was measured by studying
glance duration and by having participants perform a traffic sign identification test
after watching the video. Of those participants not looking at the traffic sign, no one
was able to detect the change. Of those participants that did glance at the changed

traffic sign, participants who detected the change had overall longer glances than the participants who did not detect the change. In case of the actual change, the glances for the Change Aware participants were even longer than in other drives. Even in case of task related changes, in this case traffic related changes, Change Blindness was still high. However, Change Blindness was lower if the image presented on the traffic sign was more deviant from the original one, when it did not fit the driving scene and when attention was raised by means of an auditory warning. Under those circumstances, all participants that glanced at the critical sign were Change Aware. However, even under those conditions, there were still people who did not glance at the critical traffic sign and were therefore Change Blind. There were no indications of implicit change detection for the Change Blind.

Chapter 13 relates the experimental results to the literature and to the elaborated task performance model. This thesis focuses on the rule-based or schemata task level, with strong top-down control. The 'failure to apprehend' at this task level is the result of a too strong top-down control, hardly leaving any room for bottom-up features. There are several approaches to avoid this. One approach would be to design roads that perfectly match the driver's expectations and fit the schemata. However, this does not seem a realistic option since the introduction of Sustainable Safety has already shown that it is not possible to implement roads that perfectly match throughout the country. Another approach would do the opposite, that is, to avoid any development of schemata or expectations by designing every road in a very different way. This approach does not seem plausible since this asks for an even stricter coordination throughout the entire country, since sufficient variation needs to be implemented from one road to the next. Also, road users would still develop expectations if they drive the same road various times. Another reason why this approach is not suitable is that it brings the driving task to the knowledge-based level of novice drivers, with an increase in task load on all roads. Novice drivers are known to have a relatively high involvement in accidents and do not have the advantages of top-down control that experienced drivers have.

A third approach would be to increase the bottom-up features in order to receive some balance with the strong top-down control. One basic measure would be to present an auditory in-vehicle warning. This most probably results in more drivers selecting the new information and taking longer glances than without this message. This would temporarily bring task performance more to the knowledge-based level of a novice driver, with the possible disadvantage of strong competition between all different visible objects. An auditory warning will only be effective if the amount of non-change related traffic signs and conspicuous visual elements in the vicinity of the changed or deviant situation is severely limited. Otherwise the disadvantage of knowledge-based performance, or competition between all items presented,

may lead to other problems. In a future scenario, a driver always carries his or her personal driver card. This card holds information about where the road user has been driving and what road situations have been changed since the last time he or she drove there. This personal card that is inserted into the car at every drive, activates a system that warns the driver for a changed traffic situation or for black spots where accidents often happen. The driver will then actively look for visual information, and if the item is then selected, it is important that the item contains sufficiently strong bottom-up features to allow deeper processing. This can be done by making the difference with the former or the expected situation as large as possible. The larger the difference between the changed situation and the original one, the higher the chance of a response. This means that as many things as possible should be changed, for instance location of a sign, its form, colour, size, type of sign and most importantly the pictogram or text shown on the sign. Also, additional measures such as road markings and additional traffic signs need to be provided. The more deviant the road situation is compared to the old situation, the stronger the bottom-up features.

Summary

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Samenvatting

Reageren op relevante visuele informatie is van cruciaal belang in bijna elke taak. Dit proefschrift bestudeert de mechanismen die ten grondslag liggen aan de zogenoemde 'failure to apprehend'; het fenomeen dat er niet gereageerd wordt op duidelijk zichtbare en relevante informatie.

Hoofdstuk 1 tot en met 6 beschrijven de literatuur op dit gebied en geven een theoretisch kader voor dit proefschrift. Hoofdstuk 7 tot en met 12 beschrijven de experimentele studies die zijn uitgevoerd. Hoofdstuk 13 geeft een aantal conclusies.

Hoofdstuk 1 beschrijft de 'failure to apprehend' in de context van 'Inattentional Blindness' en 'Change Blindness'. Inattentional Blindness is het fenomeen waarbij mensen objecten of gebeurtenissen waar ze geen aandacht aan besteden niet opmerken, alhoewel deze soms wel relevant zijn voor de taak. In het geval van Change Blindness zijn mensen zich niet bewust van een verandering die heeft plaats gevonden, alhoewel de verandering op zich duidelijk zichtbaar is. Om te kunnen reageren op informatie moet deze eerst verwerkt worden. Om informatie te verwerken moet deze eerst geselecteerd worden uit alle beschikbare informatie. De 'failure to apprehend' kan het resultaat zijn van het feit dat informatie niet is geselecteerd. **Hoofdstuk 2** beschrijft de rol van visuele selectie in het kunnen reageren op informatie. Aandacht speelt een belangrijke rol bij visuele selectie. Aandacht is het mechanisme dat informatie selecteert voor verdere cognitieve verwerking op een hoog niveau. Wanneer mensen onder normale omstandigheden een taak uitvoeren vindt selectie plaats door de ogen te richten op locaties waar zich relevante informatie bevindt. De rol van oogbewegingen in het verwerken van informatie wordt verder uitgelegd, waarbij dient te worden opgemerkt dat selectie d.m.v. het richten van de ogen naar een bepaalde plaats sterk gekoppeld is met selectie op basis van het richten van aandacht.

In **Hoofdstuk 3** wordt geïllustreerd dat er gevallen zijn waarin de 'failure to apprehend' optreedt ondanks het feit dat de informatie is geselecteerd. Er zijn soms zelfs aanwijzingen dat de informatie tot een bepaald niveau verwerkt is, zonder dat de informatie tot een reactie leidt. Dit zou dan het resultaat kunnen zijn van het feit dat de informatie niet diep genoeg verwerkt wordt, waardoor er onvoldoende prikkels zijn die kunnen leiden tot een response of dat men de informatie inmiddels vergeten is. Om deze reden zijn expliciete prestatiematen (bijvoorbeeld het vragen of mensen bepaalde informatie hebben gezien) niet altijd de beste prestatiematen. Impliciete maten, zoals hoe lang men ergens naar kijkt, reactietijden of de mogelijkheid om deze informatie impliciet te gebruiken in de rest van de taak, moeten daarom overwogen worden bij het verkrijgen van inzicht in het mechanisme dat ten grondslag ligt aan de 'failure to apprehend'.

Situaties waarin de 'failure to apprehend' het meest waarschijnlijk is worden beschreven in **Hoofdstuk 4**. Deze situaties zijn situaties waarin mensen sterke verwachtingen hebben, taken min of meer automatisch uitvoeren, in geval van vigilantie-achtige taken en taken die een hoge werklast met zich meebrengen.

Hoofdstuk 5 bespreekt de 'failure to apprehend' in de context van de rijtaak. Om de onderliggende oorzaken van de 'failure to apprehend' toe te lichten aan de hand van de drie taak-prestatiematen van Rasmussen introduceren we een uitbreiding op zijn model. Dit uitgebreide model relateert automatische taakuitvoering met wat Rasmussen 'skill-based behaviour' noemt, met een laag niveau van alertheid, aandacht en werklast. Het kost weinig tijd om de taak uit te voeren en de taak is normaliter goed geoefend. Het probleem met dit taakniveau is dat er nauwelijke ruimte is voor top-down controle. 'Rule-based' gedrag is gerelateerd aan verwachtingen en geactiveerde schemata, met een gemiddeld niveau van alertheid, aandacht en werklast. Het kost hier wat meer tijd om de taak uit te voeren en de taken zijn doorgaans minder geoefend dan taken op het skill-based niveau. Dit niveau van prestatie wordt gekenmerkt door een sterke top-down controle, met weinig ruimte voor bottom-up kenmerken. Het 'knowledge-based' niveau is gerelateerd aan het uitvoeren van nieuwe taken, met een hoog niveau van alertheid, aandacht en werklast. Het uitvoeren van de taak vraagt relatief veel tijd en de taak is nauwelijks geoefend. Informatie wordt op dit niveau bottom-up verwerkt, met bijna geen top-down controle. Alhoewel de 'failure to apprehend' plaats kan vinden op elk van deze niveaus zijn de achterliggende oorzaken duidelijk anders. Op het taakniveau van nieuwe taken is de 'failure to apprehend' hoogstwaarschijnlijk het resultaat van het niet selecteren van de juiste informatie op het juiste moment door de beperkte verwerkingscapaciteit en de afwezigheid van top-down controle, resulterend in competitie tussen alle zichtbare elementen. Op het schemata niveau is de 'failure to apprehend' waarschijnlijk het resultaat van de top-down controle die zo sterk is dat de bottom-up input van informatie die niet in de top-down schemata valt niet meer door komt. In het geval van automatisch gedrag wordt de 'failure to apprehend' ook uitgelegd door het gebrek aan top-down controle; de presentatie van een item genereert automatisch een reactie, zelfs als dat in dit geval niet de juiste reactie is.

Hoofdstuk 6 bespreekt de focus van dit proefschrift. Het verschil wordt uitgelegd tussen de rijtaak en de klassieke Change Blindness en Inattentional Blindness taken. In de meeste Change Blindness en Inattentional Blindness taken worden proefpersonen specifiek geïnstrueerd waar ze op moeten letten of wat ze moeten zoeken, terwijl dit niet het geval is bij de normale rijtaak. Ook is bij dit soort taken de informatie waar men op moet letten niet altijd relevant voor de proefpersoon, terwijl dit proefschrift zich juist richt op informatie die relevant is voor de uit te voeren taak.

Een derde verschil met Change Blindness taken is dat die zich specifiek richten op het waarnemen van een verandering, terwijl dit proefschrift zich in eerste instantie richt op het reageren op aanwezige informatie, los van of deze is veranderd. De belangrijkste onderzoeksvragen van dit proefschrift zijn: Wat is het effect van het ontwikkelen van verwachtingen op kijkgedrag en het optreden van de 'failure to apprehend', welke informatie leidt tot de 'failure to apprehend' en wat voor soort informatie kan helpen in het doorbreken van incorrecte verwachtingen die resulteren in de 'failure to apprehend'? De belangrijkste focus is de rijtaak.

Hoofdstuk 7 onderzoekt de effecten van verwachtingen op kijkduur en op de 'failure to apprehend' in twee laboratorium experimenten. Kijktijden naar en reacties op vooraf gedefinieerde targets tussen distractoren zijn gemeten in een dynamische en abstracte taakomgeving die werd getoond op een computerscherm. Proefpersonen zagen een continue stroom van stimuli met ofwel een voorspelbare ofwel een random volgorde. In de voorspelbare volgorde konden proefpersonen verwachtingen ontwikkelen over de volgorde van targets en distractoren. In die omstandigheden was de kijkduur naar targets hoger dan naar distractoren. In de random conditie waren proefpersonen niet in staat om verwachtingen te ontwikkelen over de presentatie van targets en distractoren, hetgeen resulteerde in een vergelijkbare kijkduur naar targets en distractoren. Reageren op targets ging veel sneller in de voorspelbare conditie dan in de random conditie. Het probleem met deze verwachtingen, die normaliter ervoor zorgen dat mensen sneller kunnen reageren, is het optreden van 'failure to apprehend' in het geval van incorrecte verwachtingen. Informatie die niet aansloot bij de verwachtingen werd ofwel gemist (geen reactie) ofwel de reacties waren extreem traag, veel trager dan in de random conditie. Deze resultaten laten duidelijk zien dat er een keerzijde zit aan het hebben van verwachtingen en de sterke invloed van top-down controle. Het hoofdstuk sluit af met de constatering dat deze resultaten grote implicaties kunnen hebben voor alle taken die sterke top-down controle hebben over visuele selectie en informatieverwerking, zoals monitoring taken of autorijden. In dit soort taken kunnen de 'failure to apprehend' en sterk vertraagde reacties dramatische gevolgen hebben.

Hoofdstuk 8 brengt het effect van verwachtingen op reactietijden, reactiefouten en kijktijden in kaart, wederom in een laboratorium omgeving. In een dynamische en abstracte computer gesimuleerde omgeving reageerden proefpersonen op vooraf gedefinieerde targets tussen distractors, die wederom in een continue stroom werden gepresenteerd. De eigenschappen van de stimuli waren anders dan die gebruikt in Hoofdstuk 7. Sporadisch moest een proefpersoon reageren op een target die niet op dat moment werd verwacht of men moest juist niet reageren wanneer een target niet verscheen die wel werd verwacht. Ook hier vonden we dat de kijktijd voor targets

langer was dan voor distractoren. Reactietijden voor onverwachte targets waren veel langer dan reactietijden op verwachte targets. Veel fouten werden gemaakt wanneer onverwachte informatie werd gepresenteerd, met de meeste fouten wanneer men een reactie moest inhiberen. Er was geen verschil in kijktijd tussen proefpersonen die correct reageerden en de proefpersonen die niet correct reageerden in het geval van onverwachte informatie. De aanwezigheid van onverwachte informatie veranderde de kijkstrategie van proefpersonen niet. Ook hier laten de resultaten een sterk negatieve invloed zien van verwachtingen en top-down controle met gevolgen voor taken als het inspecteren van producten op een lopende band of voor luchtverkeersleiders.

Hoofdstuk 9 onderzoekt het effect van verwachtingen op kijktijden en het reageren op onverwachte informatie binnen de rijtaak. Proefpersonen reden in een low-cost rijsimulator terwijl hun oogbewegingen werden geregistreerd. In bepaalde condities raakten proefpersonen bekend met een bepaalde omgeving door dezelfde weg verschillende malen per dag te rijden gedurende meerdere dagen. Het onderzoek liet zien dat het herhaald rijden op dezelfde weg de bekendheid met de weg verhoogde en dat dit effect had op het kijkgedrag van bestuurders. Met toenemende bekendheid met de weg keken de proefpersonen minder lang naar de verkeersborden langs de route, terwijl men beter wist welke verkeersborden er waar langs de weg werden getoond. Wanneer de verkeerssituatie werd gewijzigd (een voorrangsweg werd veranderd in een situatie waarin men voorrang moest verlenen) zonder een specifieke instructie, keken weggebruikers naar het bord dat de nieuwe voorrangssituatie aangaf maar men verwerkte dit niet voldoende om tot een reactie te komen. Het herhaald blootstellen aan dezelfde weg resulteerde in veel inadequate reacties op de verandering in voorrang, ondanks het feit dat er een nieuw verkeersbord stond en dat er haaientanden werd getoond die hiervoor niet aanwezig waren. Het gevonden resultaat, dat incorrecte verwachtingen ervoor kunnen zorgen dat automobilisten belangrijke informatie missen ondanks dat ze er naar kijken, is ook relevant voor andere monitoring taken.

Hoofdstuk 10 bestudeert kijktijden bij het bekend raken met een bepaalde wegomgeving. Omdat al bekend was dat kijktijden voor verkeersborden afnemen in een gesimuleerde omgeving onderzocht deze studie of dit ook het geval is voor echt rijden en voor een video-conditie. In de video-conditie was een video opgenomen vanuit het oogpunt van een automobilist. Terwijl proefpersonen de video bekeken moesten ze net doen alsof zij de bestuurder waren van de auto, dus online meesturen en remmen. Eén van de belangrijkste resultaten van deze studie was dat de afname in kijktijd voor verkeersgerelateerde objecten met een toenemende bekendheid met de weg, zoals gevonden in een gesimuleerde omgeving, ook werd gevonden in de echte

rijtaak. Een tweede belangrijke uitkomst is dat deze afname ook werd gevonden voor de video-conditie. Dit betekent dat over alle objecten genomen de twee methoden tot vergelijkbare resultaten leiden wanneer we de kijkduur voor objecten bestuderen. Voor kijkfrequentie geldt dat mensen wat vaker naar een object kijken wanneer men video kijkt dan wanneer men in het echt rijdt. De afname in kijkfrequentie is minder geleidelijk dan die voor kijkduur.

De afname in kijkduur over dagen heen was redelijk vergelijkbaar tussen het bekijken van de video en het echte rijden. Echter, er waren wel verschillen in kijktijd tussen de twee condities voor individuele objecten. Dit betekent dat de video-configuratie niet geschikt is voor het identificeren van objecten die in het echt de langste en kortste kijktijden zouden hebben. Alhoewel er objecten zijn die zowel in de video-conditie als in het echt de langste of juist de kortste kijktijden hebben, is er geen exclusieve overlap. Daarom is voorzichtigheid geboden wanneer men video gebruikt in plaats van de echte rijtaak wanneer men kijktijden en kijkfrequenties voor verkeersgerelateerde objecten onderzoekt. De video methode is geschikt voor exploratief onderzoek waarin gekeken wordt naar kijkduur voor verkeersobjecten en om het effect te onderzoeken van bekendheid met een wegomgeving op kijktijd zonder geïnteresseerd te zijn in de exacte kijkduur in echte rijomstandigheden.

In **Hoofdstuk 11** wordt een rijsimulatorstudie beschreven die de effecten van bekendheid met een weg onderzoekt op de 'failure to apprehend'. De centrale vraag was of bekendheid met een weg resulteert in de 'failure to apprehend' en of de 'failure to apprehend' vooral voorkomt wanneer mensen meerdere malen precies dezelfde weg rijden of ook wanneer er dingen in de wegomgeving veranderen. Om de 'failure to apprehend' te bestuderen werd een verandering in het wegontwerp van de ene rit op de andere aangebracht. In deze studie werd een normale weg veranderd in een 'Verboden in te rijden' weg nadat mensen bekend waren geraakt met de weg. Proefpersonen werden op verschillende manieren gewaarschuwd voor deze situatie, van het tonen van alleen een bord tot auditieve in-voertuig boodschappen. De rijsimulatorstudie liet zien dat er geen verschil was in het optreden van de 'failure to apprehend' tussen de gevarieerde wegomgeving en exact dezelfde wegomgeving. Sterker nog, de 'failure to apprehend' was niet eens het negatieve gevolg van dezelfde of een vergelijkbare weg meerdere malen berijden, maar het gevolg van verwachtingen die automobilisten al hadden tijdens de eerste rit. Dit geeft aan dat er situaties zijn waarin de 'failure to apprehend' niet het resultaat is van bekendheid met een weg, maar meer het resultaat van verkeerde verwachtingen die worden opgeroepen door het wegontwerp zelf. Zelfs tijdens de eerste rit verwachtte men geen 'Verborden in te rijden' situatie, wat leidde tot het inrijden van deze weg. Het toevoegen van informatie om weggebruikers te wijzen op de gewijzigde situatie doet de 'failure to apprehend' afnemen. Alhoewel er minder fouten werden gemaakt wanneer een geel bord werd toegevoegd dat aangaf dat de verkeerssituatie was

gewijzigd kwam de 'failure to apprehend' in die omstandigheden nog steeds voor. Alleen in het geval van een auditieve in-voertuig waarschuwing was de 'failure to apprehend' niet aanwezig.

Hoofdstuk 12 onderzoekt de 'failure to apprehend' in een rijtaak gerelateerde context met behulp van een Change Blindness taak. Het doel van het experiment was om te onderzoeken hoe groot het probleem van Change Blindness is in het geval van taak gerelateerde veranderingen. Met taak gerelateerde veranderingen doelen we hier op veranderingen gerelateerd aan de taak die mensen uitvoeren. In dit geval werden automobilisten geïnstrueerd om een verandering in een verkeersgerelateerd item te zoeken, in dit geval een verandering in een verkeersbord. Een ander doel was om te onderzoeken hoe het type verandering Change Blindness beïnvloedt en om de rol van kijktijden op Change Blindness te bestuderen. De studie werd uitgevoerd door automobilisten video's, gefilmd vanuit het oogpunt van de bestuurder, te laten bekijken, waarin 6 ritjes werden getoond van eenzelfde blokje rond. Proefpersonen werden geïnstrueerd om goed te letten op verkeersgerelateerde zaken en om zich voor te stellen dat zij de bestuurder waren van de auto. Er werd ook verteld dat ze moesten zoeken naar een verkeersgerelateerde verandering. Kijktijden naar verkeersborden werden gemeten net als Change Blindness (zijn proefpersonen in staat om de verandering expliciet op te merken). In rit 6 werd één van de verkeersborden veranderd in een ander verkeersbord. Er waren vijf verschillende condities, inclusief een controle conditie zonder een verandering aan het verkeersbord. In de vier experimentele condities werd het originele verkeersbord vervangen door een ander officieel verkeersbord. Impliciete verwerking van de verandering werd gemeten door het registreren van kijktijden en door proefpersonen een verkeersbord identificatie test te laten uitvoeren na alle video's te hebben bekeken. Van de proefpersonen die niet naar het veranderde bord keken was niemand in staat om de verandering te rapporteren. Van de proefpersonen die wel naar het veranderde bord keken hadden proefpersonen die de verandering konden rapporteren in alle ritten langere kijktijden dan de proefpersonen die de verandering uiteindelijk niet konden rapporteren. In het geval van de eigenlijke verandering waren de kijktijden voor diegenen die de verandering expliciet konden rapporteren nog langer dan in eerdere ritten. Zelfs in het geval van taakgerelateerde veranderingen, in dit geval dus verkeersgerelateerde veranderingen, was Change Blindness relatief hoog. Change Blindness was lager wanneer het plaatje dat werd gepresenteerd op het bord meer afweek van het origineel, wanneer het minder goed in de omgeving paste en wanneer extra aandacht werd gevraagd door een auditieve waarschuwing. In die omstandigheden rapporteerden alle proefpersonen die naar het bord keken ook de verandering. Echter, zelfs in die omstandigheden waren er nog mensen die niet naar het veranderde bord keken en daarom dus Change Blind waren. Er waren geen aanwijzingen voor impliciete waarneming van de verandering.

In **Hoofdstuk 13** worden de experimentele resultaten in verband gebracht met de literatuur en het uitgebreide taak prestatie model. Dit proefschrift focust op het rule-based ofwel het schemata niveau, met sterke top-down controle. De 'failure to apprehend' op dit taakniveau is het resultaat van een te sterke top-down controle die nauwelijks ruimte laat voor bottom-up kenmerken. Er zijn een aantal manieren waarop dit zou kunnen worden voorkomen. Een manier van aanpak zou zijn om alleen nog maar wegen te ontwerpen die perfect aansluiten bij de verwachingen van weggebruikers en passen binnen de schemata. Dit lijkt echter geen realistische optie omdat het introduceren van Duurzaam Veilig al heeft laten zien dat het niet mogelijk is om wegen te implementeren door het hele land die perfect op elkaar aansluiten. Een andere aanpak zou het tegenovergestelde kunnen zijn, om de ontwikkeling van schemata of verwachtingen helemaal tegen te gaan door elke weg weer compleet anders te ontwerpen. Ook deze aanpak lijkt niet realistisch aangezien het realiseren van voldoende variatie tussen de verschillende wegen een nog sterkere landelijke coördinatie vergt. Ook zullen weggebruikers nog steeds verwachtingen opbouwen wanneer ze bekend raken met een bepaalde weg. Een andere reden waarom deze aanpak niet de juiste is, is dat het het niveau van de rijtaak overal terugbrengt naar het knowledge-based niveau van een onervaren weggebruiker, met een bijbehorende hoge werklast. Onervaren weggebruikers hebben een relatief hoge ongevalskans en hebben niet de voordelen van de top-down controle die ervaren weggebruikers hebben.

Een derde manier van aanpak zou zijn om de bottom-up kenmerken te versterken zodat er een betere balans ontstaat met de sterke top-down controle. Een manier is het gebruiken van een auditieve in-voertuig waarschuwing. Dit zorgt er hoogstwaarschijnlijk voor dat meer weggebruikers de nieuwe informatie selecteren en langer kijken dan zonder deze waarschuwing. Dit zou het taakniveau tijdelijk terug brengen naar het knowledge-based niveau van een onervaren weggebruiker, mogelijk met het nadeel van sterke competitie tussen alle verschillende objecten die te zien zijn. Een auditieve waarschuwing zal alleen effectief zijn wanneer de hoeveelheid andere visuele informatie beperkt is. Anders leidt het nadeel van knowledge-based prestatie, ofwel competitie tussen alle gepresenteerde informatie, tot andere problemen. In een toekomstscenario draagt een bestuurder altijd een persoonlijke kaart met zich mee. Deze kaart bevat informatie over waar de weggebruiker heeft gereden en welke verkeerssituaties veranderd zijn sinds de laatste keer dat hij of zij daar heeft gereden. Deze persoonlijke kaart wordt in de auto ingevoerd bij elke rit, en deze activeert een systeem dat de bestuurder waarschuwt voor de gewijzigde situatie maar wellicht ook voor zogenaamde black spots waar veel ongevallen gebeuren. Een bestuurder zal dan actief op zoek gaan naar informatie, en wanneer deze informatie wordt geselecteerd is het belangrijk dat het item voldoende sterke bottom-up features bevat om diep verwerkt te worden. Dit kan bereikt worden door het verschil met de oude of de

verwachte informatie zo groot mogelijk te maken. Hoe groter het verschil tussen de veranderde en de originele situatie, hoe groter de kans op een reactie. Dit betekent dat zo veel mogelijk veranderd moet worden, zoals bijvoorbeeld de plaats van een bord, de vorm, kleur, grootte, type bord en zeer belangrijk het pictogram of de tekst die wordt getoond. Ook moeten extra maatregelen zoals wegmarkering of extra verkeersborden worden getoond. Hoe afwijkender de wegsituatie is in vergelijking met de oude situatie, hoe sterker de bottom-up kenmerken.

References

References

Abrams, R.A. & Jonides, J. (1988). Programming saccadic eye movements. Journal of Experimental Psychology: Human Perception and Performance, 14(3), 428-443.

Alferdinck, J.W.A.M. & Hoedemaeker, M. (2004). Implementation and testing of the driving scenarios in the TNO driving simulator. TNO Memorandum TM-04-M062. Soesterberg, The Netherlands.

Allen, F. (1926). The persistence of vision. American Journal of Physiological Optics, 7, 439-457.

Allport, D.A. (1987). Selection for action: Some behavioural and neurophysiological considerations of attention and action. In: H. Heuer and A.F. Sanders (Eds.) Perspectives on perception and action, 395–419. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Allport, D.A. (1993). Attention and control. Have we been asking the wrong questions? A critical review of twenty-five years. In: D.E. Meyer and S. Kornblum (Eds.) Attention and performance XIV: Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience, 183–218. Cambridge, MA: MIT Press.

Anderson, J.R. (1985). Cognitive psychology and its implications. New York: Freeman.

Andriessen, J.J. & de Voogd, A.J. (1973). Analysis of eye movement patterns in silent reading. IPO Annual Progress Report, 8, 29-34.

Angelone, B.L., Levin, D.T. & Simons, D.J. (2003). The relationship between change detection and recognition of centrally attended objects in motion pictures. Perception, 32, 947-962.

Antes, J.R. (1974). The time course of picture viewing. Journal of Experimental Psychology, 103, 62-70.

Antes, J.R. & Penland, J.G. (1981). Picture context effects on eye movement patterns. In: D.F. Fisher, R.A. Monty and J.W. Senders (Eds.) Eye Movements: Cognition and Visual Perception. Hillsdale, NJ: Lawrence Erlbaum Associates.

Averbach, E. & Coriell, A.S. (1961). Short-term memory in vision. Bell Systems Technical Journal, 40, 309-328.

Avons, S.E. & Phillips, W.A. (1980). Visualization and memorization as a function of display time and poststimulus processing time. Journal of Experimental Psychology: Human Learning and Memory, 6(4), 407-420.

Baddeley, A. (1986). Working memory. Oxford: Clarendon.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? Trends in Cognitive Sciences, 4(11), 417-423.

Baddeley, A. (2002). Fractionating the Central Executive. In: D.T.S.A.R.T. Knight (Ed.) Principles in Frontal Lobe Function, 246-260. New York: Oxford Press.

Baddeley, A.D., Logie, R., Nimmo-Smith, I. & Brerefon, N. (1985). Components of fluent reading. Journal of Memory and Language, 24, 119–131.

Bahcall, D.O. & Kowler, E. (1999). Attentional interference at small spatial separations. Vision Research, 39, 71–86.

Baker, C.H. (1960). Observing behavior in a vigilance task. Science, 132, 674-675.

Bar, M. & Biederman, I. (1998). Subliminal visual priming. Psychological Science, 9, 464-469.

Barrett, D.J.K, Bradshaw, M.F. & Rose, D. (2003). Endogenous shifts of covert attention operate within multiple coordinate frames: Evidence from a feature-priming task. Perception, 32, 41-52.

Bartlett, F.C. (1932). Remembering: A study in experimental social psychology. London: Cambridge University Press.

Beck, M.R., Angelone, B.L. & Levin, D.T. (2004). The role of knowledge about the probability of change in detecting changes. Journal of Experimental Psychology: Human Perception and Performance, 30, 778-791.

Beck, M.R., Levin, D.T. & Angelone, B. (2007). Change blindness blindness: Beliefs about the roles of intention and scene complexity in change detection. Consciousness and Cognition, 16, 31-51.

Beck, D.M., Rees, G., Frith, C.D. & Lavie, N. (2001). Neural correlates of change detection and change blindness. Nature Neuroscience, 4, 645-650.

Becker, W. (1991). Saccades. In: R.H.S. Carpenter (Ed.) Eye movements. Boston: CRC Press, 95-137.

Becker, M.W., Pashler, H. & Anstis, S.M. (2000). The role of iconic memory in change-detection tasks. Perception, 29, 273-286.

Becklen, R. & Cervone, D. (1983). Selective looking and the noticing of unexpected events. Memory & Cognition, 11, 601–608.

Bhise, V.D. & Rockwell, T.H. (1973). Development of a methodology for evaluating road signs. Project EES-315B Final Report, Engineering Experiment Station Bulletin 207. Engineering Publications, The Ohio State University, Columbus, OH.

Bichot, N.P. (2001). Attention, eye movements, and neurons: Linking physiology and behaviour. In: M. Jenkin and L. Harris (Eds.) Vision & Attention. Springer-Verlag, New York, pp 209-232.

Biederman, I. (1981). On the semantics of a glance at a scene. In: M. Kubovy & JR Pomerantz (Eds.) Perceptual Organization, 213-263. Hillsdale, New Jersey: Lawrence Erlbaum

Biederman, I., Mezzanotte, R.J. & Rabinowitz, J.C. (1982). Scene perception: Detecting and judging objects undergoing relational violations. Cognitive Psychology, 14, 143-177.

Biederman, I., Mezzanotte, R.J., Rabinowitz, J.C., Francolini, C.M. & Plude, D. (1981). Detecting the unexpected in photo interpretation. Human Factors, 23, 153-163.

Biederman, I., Rabinowitz, J.C., Glass, A.L. & Stacey, E.W.J. (1974). On the information extracted from a glance at a scene. Journal of Experimental Psychology, 103(3), 597-600.

Blackmore, S.J., Brelstaff, G., Nelson, K. & Troscianko, T. (1995). Is the richness of our visual world an illusion? Transsaccadic memory for complex scenes. Perception, 24, 1075–1081.

Boyce, S.J. & Pollatsek, A. (1992). Identification of objects in scenes: The role of scene background in object naming. Journal of Experimental Psychology: Learning, Memory and Cognition, 18, 531–543.

Boyce, S.J., Pollatsek, A. & Rayner, K. (1989). Effects of background information on object indentification. Journal of Experimental Psychology: Human Perception and Performance, 15, 556-566.

Boynton, R.M. & Bush, W.R. (1956). Recognition of forms against a complex background. Journal of the Optical Society of America, 46, 758.

Bradley, B.P., Mogg, K. & Millar, N.H. (2000). Covert and overt orienting of attention to emotional faces in anxiety. Cognition and Emotion, 14(6), 789-808.

Braun, J. (1994). Visual search among items of different salience: removal of visual attention mimics a lesion in extrastriate area V4. Journal of Neuroscience, 14, 554–567.

Braun, J. (2001). It's great but not necessarily about attention. Psyche, 7(6), March. http://psyche.cs.monash.edu.au/v7/psyche-7-06-braun.html

Braun, J. & Julesz, B. (1998). Withdrawing attention at little or no cost: Detection and discrimination tasks. Perception and Psychophysics, 60, 1–23.

Broadbent, D.E. (1957). A mechanical model for human attention and immediate memory. Psychological Review, 64(3), 205-215.

Broadbent, D.E. (1958). Perception and communication. London: Pergamon.

Brown, I.D. (2005). Review of the 'Looked but Failed to See' accident causation factor. Road Safety Research Report No. 60. Department for Transport, London.

Burns, P.C., Parkes, A., Burton, S., Smith, R.K., Burch, D. (2002). How dangerous is driving with a mobile phone? Benchmarking the impairment to Alcohol. Report TRL 547. TRL, Wokingham.

Buswell, G.T. (1935). How people look at pictures. Chicago: Univ. Chicago Press.

Caird, J.K., Edwards, C.J., Creaser, J.I. & Horrey, W.J. (2005). Older driver failures of attention at intersections: Using change blindness methods to assess turn decision accuracy. Human Factors, 47(2), 235-249.

Cairney, P. & Catchpole, J. (1996). Patterns of perceptual failures at intersections of arterial roads and local streets. In: A.G. Gale, I.D. Brown, C.M. Haslegrave and S.P. Taylor (Eds.) Vision in Vehicles V, 87-94. Amsterdam: Elsevier (North-Holland).

Callaway, E. Tueting, P. & Koslow, S. (1978). Brain event-related potentials in man. New York: Academic Press.

Carrasco, M., Evert, D.L., Chang, I. & Katz, S.M. (1995). The eccentricity effect: Target eccentricity affects performance on conjunction searches. Perception and Psychophysics, 57, 1241–1261.

Carroll, P. & Slowiaczek, M.L. (1986). Constraints on semantic priming in reading: a glance duration analysis. Memory & Cognition, 14(6), 509-522.

Cavanagh, P. (2004). Attention routines and the architecture of selection. In: M.I. Posner (Ed.) Cognitive Neuroscience of Attention, 13-28. The Guilford Press: New York.

Cave, K.R. & Bichot, N.P. (1999). Visuospatial attention: Beyond a spotlight model. Psychonomic Bulletin & Review, 6, 204-223.

Cave, K.R. & Wolfe, J.M. (1990). Modelling the role of parallel processing in visual search. Cognitive Psychology, 22, 225-271.

Cepeda, N.J., Cave, K.R., Bichot, N.P. & Kim, M. (1998). Spatial selection via feature-driven inhibition of distractor locations. Perception & Psychophysics, 60, 727–746.

Chapman, P. & Underwood, G. (1998). Visual search of driving situations: Danger and expertise. Perception, 27, 951-964.

Chase, W.G. & Simon, H.A. (1973a). The mind's eye in chess. In: W. G. Chase (Ed.) Visual information processing, 215–281. New York: Academic Press.

Chase, W.G. & Simon, H.A. (1973b). Perception in chess. Cognitive Psychology, 4, 55-81.

Chen, Z. (1998). Inattentional amnesia: Evidence of perception without awareness. Investigative Ophthalmology and Visual Science, 39(4), S629.

Christie, J. & Klein, R. (1996). Assessing the evidence for novel popout. Journal of Experimental Psychology: General, 125, 201-207.

Chun, M.M. & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. Cognitive Psychology, 36, 28-71.

Cohen, B. (1981). Vestibular and oculomotor physiology. International Meeting of the Barany Society. Annals of the New York Academy of Sciences, 374.

Cole, B.L. & Jenkins, S.E. (1982). The effect of the density of background elements on the conspicuity of objects. Vision Research, 22(10), 1241-1252.

Consiglio, W., Driscoll, P., Witte, M. & Berg, W. (2003). Effect of cellular telephone conversations and other potential interference on reaction time in braking response. Accident Analysis and Prevention, 35(4), 495-500.

Corbetta, M. (1998). Functional anatomy of visual attention in the human brain: Studies with Positron Emission Tomography. In: R. Parasuraman (Ed.) The attentive brain, 95-122. Cambridge MA: MIT Press.

Coren, S., Ward, L.M. & Enns, J.T. (1994). Sensation and perception. Harcourt Brace College Publishers, New York.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. Behavioural and Brain Sciences, 24, 87-114.

Crundall, D., Chapman, P., Phelps, N. & Underwood, G. (2003). Eye movements and hazard perception in police pursuit and emergency response driving, Journal of Experimental Psychology: Applied, 9 (3), 163-174.

Davies, D.R. & Parasuraman, R. (1982). The psychology of vigilance. London: Academic Press.

De Graef, P. (1992). Scene-context effects and models of real-world perception. In: K. Rayner (Ed.) Eye movements and visual cognition: Scene perception and reading, 243-259. New York: Springer-Verlag.

De Graef, P., Christiaens, D. & d'Ydewalle, G. (1990). Perceptual effects of scene context on object identification. Psychological Research, 52, 317-329

De Groot, A.D. (1978). Thought and choice in chess (2nd Edition). The Hague: Mouton.

Dehaene, S., Naccache, L., Cohen, L., Le Bihan, D., Mangin, J-F., Poline, J-B. & Riviere, D. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. Nature Neuroscience, 4, 752-758.

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P-F. & Le Bihan, D. (1998). Imaging unconscious semantic priming. Nature, 395, 597-600.

De Jong, J. & Duijnhower, W. (1972). Conspicuity area and background density: explorative experiments. Institute for Perception Research, Eindhoven, the Netherlands.

Dember, W.N. & Warm, J.S. (1979). Psychology of perception (2nd Edition). New York: Holt, Rinehart and Winston.

Desimone, R. & Duncan, J. (1995). Neural mechanisms of selective visual attention. Annual Review of Neuroscience, 18, 193-222.

Deubel, H. & Schneider, W.X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. Vision Research, 6, 1827-1837.

Deutsch, J.A. & Deutsch, D. (1963). Attention: some theoretical considerations. Psychological Review, 70, 80-90.

Dick, A.O. (1971). On the problem of selection in short-term visual (iconic) memory. Canadian Journal of Psychology, 25(3), 250-263

Dmytryk, E. (1984). On film editing. An introduction to the art of film construction. Focal Press, Butterworth Publishers, Stoneham, MA.

Donchin, E. (1979). Event-related brain potentials: A tool in the study of human information processing. In: H. Begleiter (Ed.) Evoked potentials in psychiatry, 13-75. New York: Plenum Press.

Donchin, E. & Coles, M.G.H. (1998). Is the P300 component a manifestation of context updating? Behavioral and Brain Sciences, 11, 357-374.

Donchin, E., Ritter, W. & McCallum, C. (1978). Cognitive psychophysiology: The endogenous components of the ERP. In: E. Callaway, P. Tueting and S. Koslow (Eds.) Brain event-related potentials in man, 349-441. New York, Academic Press.

Draskoczy, M. (1989). Bus driver behaviour at rail-highway grade crossings. In: T. Rothengatter and R. De Bruin (Eds.) Road User Theory and Research. Maastricht, The Netherlands: Van Gorcum.

Duffy, E. (1957). The psychological significance of the concept of "arousal" or "activation". Psychological Review, 64(5), 265-275.

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. Psychological Review, 87, 272-300.

Duncan, J. & Humphreys, G.W. (1989). Visual search and stimulus similarity. Psychological Review, 96 (3), 433-458.

Egeth, H.E. & Yantis, S. (1997). Visual attention: Control, representation, and time course. Annual Review of Psychology, 48, 269-297.

Eimer, M. & Mazza, V. (2005). Electrophysiological correlates of change detection. Psychophysiology, 42(3), 328-342.

Ellis, S.R. & Stark, L. (1978). Eye movements while viewing Necker cubes. Perception, 7, 575-581.

Engel, F.L. (1974). Visual conspicuity and selective background interference in eccentric vision. Vision Research, 14, 459.

Engel, F.L. (1977). Visual conspicuity. Visual search and fixation tendencies of the eye. Vision Research, 17, 95.

References

Ericsson, K.A. & Simon, H.A. (1980). Verbal reports as data. Psychological Review, 87(3), 215-251.

Eriksen, C.W. & Hofman, J.E. (1972). Temporal and spatial characteristics of selective encoding from visual displays. Perception & Psychophysics, 12, 201-204.

Eriksen, C.W. & Hofman, J.E. (1973). The extent of processing of noise elements during selective encoding from visual displays. Perception & Psychophysics, 14, 155-160.

Evans, L. (2004). Traffic Safety. Bloomfield Hills, MI: Science Serving Society.

Fernandez-Duque, D., Baird, J.A. & Posner, M.I. (2000). Awareness and metacognition. Consciousness and Cognition, 9, 324–326.

Fernandez-Duque, D., Grossi, G., Thornton, I.M. & Neville, H.J. (2003). Representation of change: Separate Electrophysiological Markers of Attention, Awareness, and Implicit Processing. Journal of Cognitive Neuroscience, 15(4), 491-507.

Fernandez-Duque, D. & Thornton, I.M. (1999). Unconscious priming of object change. Paper presented at the 22nd European Conference on Visual Perception, Trieste, Italy, 21-26 August.

Fernandez-Duque, D. & Thornton, I.M. (2000). Change detection without awareness: Do explicit reports underestimate the representation of change in the visual system? Visual Cognition, 7, 323–344.

Fernandez-Duque, D. & Thornton, I.M. (2002). Explicit mechanisms do not account for implicit localization and identification of change: An empirical reply to Mitroff et al. (2002). Journal of Experimental Psychology: Human Perception &Performance, 29, 846-858.

Findlay, J.M. (1981). Spatial and temporal factors in the predictive generation of saccadic eye movements. Vision Research, 21, 347–354.

Findlay, J.M. (1997). Saccade target selection in visual search. Vision Research, 37, 617–631.

Fischer B. & Weber H. (1993). Express saccades and visual attention. Behavioral & Brain Sciences, 16(3), 553-567.

Fisher, J. (1992). Testing the effect of road traffic signs information value on driver behavior. Human Factors, 34(2), 231-237.

Fisher, D.F., Monty, R.A. & Perlmuter, L.C. (1978). Visual recognition memory for binary pictures: Another look. Journal of Experimental Psychology: Human Learning and Memory, 4, 158-164.

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Fisk, A.D., Lee, M.D. & Rogers, W.A. (1991). Recombination of automatic processing components: the effects of transfer, reversal, and conflict situations. Human Factors, 33(3), 267-280.

Fiske, S.T. & Taylor, S.E. (1991). Social cognition (2nd Edition). New York: McGraw-Hill.

Fitts, P.M. & Posner, M.I. (1967). Learning and skilled performance in human performance. Belmont CA: Brock-Cole.

Forbes, T.W., Fry, J.P., Joyce, R.P. & Paine, R.F. (1968a). Letter and sign contrast, brightness and size effects on visibility research. Highway Research Record, 216, 48.

Forbes, T.W., Fry, J.P., Joyce, R.P. & Paine, R.F. (1968b). Colour and brightness factors in simulated and full-scale traffic sign visibility. Highway Research Record, 216, 55.

Francis, G. (1996). Cortical dynamics of lateral inhibition: Visual persistence and ISI. Perception & Psychophysics, 58(7), 1103-1109.

Frankmann, J.P. & Adams, J.A. (1962). Theories of Vigilance. Psychological Bulletin, 459, 257-272.

Friedman A. (1979). Framing pictures: the role of knowledge in automatized encoding and memory for gist. Journal of Experimental Psychology: General, 108, 316-355.

Friedman, A. & Liebelt, L.S. (1981). On the time course of viewing pictures with a view towards remembering. In: D.F. Fisher, R.A. Monty and J.W. Senders (Eds.) Eye Movements, Cognition and Visual Perception, 137-156. Hillsdale, N.J.: Lawrence Erlbaum.

Gaarder, K.R. (1975). Eye movements, vision and behavior. A hierarchical visual information processing model. New York: John Wiley & Sons.

Gale, A.G. & Findlay, J.M. (1983). Eye movement pattern in viewing ambiguous figures. In: R. Groner, C. Menz, D.F. Fischer and R.A. Monty (Eds.) Eye Movements and Psychological Functions, 145-168. Hillsdale, N.J.: Lawrence Erlbaum.

Gegenfurtner, K.R. & Sperling, G. (1993). Information transfer in iconic memory experiments. Journal of Experimental Psychology: Human Perception and Performance, 19(4), 845-866.

Geisler, W.A. & Chou, K.L. (1995). Separation of low-level and high-level factors in complex tasks: visual search. Psychological Review, 102(2), 356-378.

Gibson, J.J. & Crooks, L.E. (1938). A theoretical field-analysis of automobile-driving. American Journal of Psychology, 51, 453-471.

Godijn, R. & Pratt, J. (2002). Endogenous saccades are preceded by shifts of visual attention: Evidence from cross-saccadic priming effects. Acta Psychologica, 110, 83–102.

Godijn, R. & Theeuwes, J. (2002). Parallel programming of exogenous and endogenous saccades: Evidence for a competitive integration model. Journal of Experimental Psychology: Human Perception and Performance, 28, 1039–1054.

Godijn, R. & Theeuwes, J. (2004). The relationship between inhibition of return and saccade trajectory deviations. Journal of Experimental Psychology: Human Perception and Performance, 30(3), 538–554.

Godthelp, J. (1980). Het zien van verkeersborden bij nacht [The recognition of traffic control signs during nighttime]. TNO Report IZF 1980-C21. Soesterberg, the Netherlands.

Godthelp, J. (1988). The limits of path error-neglecting in straight lane driving. Ergonomics, 31, 609-619.

Graves, R.E. & Jones, B.S. (1992). Conscious visual perceptual awareness vs. non-conscious visual spatial localisation examined with normal subjects using possible analogues of blindsight and neglect. Cognitive Neuropsychology, 9(6), 487-508.

Green, M. (2000). Human Error in Road Accidents. Swiss Reinsurance Canada Review, September, 1-14.

Green, M. (2004). Inattentional Blindness and conspicuity. Internet Seminar. Link: www.visualexpert.com/Resources/inattentionalblindness.html

Green, D.M. & Swets, J.A. (1966). Signal detection theory and psychophysics. New York: Wiley.

Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In: K. Akins (Ed.) Perception Volume 2, 89-110. Vancouver Studies in Cognitive Science, New York: Oxford University Press.

Groff, L.S. & Chaparro, A. (2003). Effects of experience and task relevance on the ability to detect changes in a real-world task. Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting, 1605-1609.

Haines, R. F. (1991). A breakdown in simultaneous information processing. In: G. Obrecht & L. W. Stark (Eds.) Presbyopia research: From molecular biology to visual adaptation, 171–175. New York: Plenum.

Häkkinen, S. (1965). Perception of Highway Traffic Signs. Report from Talja, No. 1. Finland: The Central Organisation for Traffic Safety.

Harris, W. (1977). Fatigue, circadian rhythm, and truck accidents. In: R. Parasuraman, D.R. Davies and R.R. Mackie (Eds.) Vigilance: Theory, Operational Performance and Physiological Correlates, 133-146. New York: Plenum Press.

Hasher, L.Y & Zacks, R.T. (1979). Automatic and effortful processes in memory. Journal of Experimental Psychology, 108, 386-388.

Hayhoe, M.M. (2000). Vision using routines: a functional account of vision. Visual Cognition, 7, 43-64.

Hayhoe, M.M., Bensinger, D.G. & Ballard, D.H. (1998). Task constraints in visual working memory. Vision Research, 38, 125-137.

Hebb, D.O. (1955). Drives and the CNS (conceptual nervous system). Psychological Review, 62, 243-254.

Henderson, J.M. (1988). Visual attention and the acquisition of extrafoveal information during eye fixations. Dissertation Univerisity of Massachusetts Amherst.

Henderson, J.M. (1992a). Visual attention and eye movement control during reading and picture viewing. In: K. Rayner (Ed.) Eye Movements and Visual cognition: Scene Perception and Reading, 260-283. New York: Springer-Verlag.

Henderson, J.M. (1992b). Object identification in context: The visual processing of natural scenes. Canadian Journal of Psychology, 46 (Special Issue), 319-341.

Henderson, J.M. (1996). Visual attention and the attention-action interface. In: K. Akins (Ed.) Perception: Vancouver Studies in Cognitive Science 5, 290-316. Oxford: Oxford University Press.

Henderson, J.M. (2003). Human gaze control during real-world scene perception. Trends on Cognitive Sciences, 7(11), 498-504.

Henderson, J.M. & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. Journal of Experimental Psychology: Human Perception and Performance, 16, 417-429.

Henderson, J.M. & Hollingworth, A. (1998). Eye movements during scene viewing: An overview. In: G. Underwood (Ed.) Eye Guidance in Reading and Scene Perception, 269-283. Oxford: Elsevier.

References

Henderson, J.M. & Hollingworth, A. (1999a). The role of fixation position in detecting scene changes across saccades. Psychological Science, 10, 438-443

Henderson, J.M. & Hollingworth, A. (1999b). High-level scene perception. Annual Review of Psychology, 50, 243–271.

Henderson, J.M. & Hollingworth, A. (2003a). Eye movements and visual memory: Detecting changes to saccade targets in scenes. Perception & Psychophysics, 65, 58-71.

Henderson, J.M. & Hollingworth, A. (2003b). Global transsaccadic change blindness during scene perception. Psychological Science, 14 (5), 493-497.

Henderson, J.M., Pollatsek, A. & Rayner, K. (1987). Effects of foveal priming and extrafoveal preview on object identification. Journal of Experimental Psychology: Human Perception and Performance, 13, 449-463.

Henderson J.M., Pollatsek, A. & Rayner, K. (1989). Covert visual attention and extrafoveal information use during object identification. Perception & Psychophysics, 45, 196-208.

Henderson J.M., Weeks, P.A. Jr & Hollingworth, A. (1999). The effects of semantic consistency on eye movements during scene viewing. Journal of Experimental Psychology: Human Perception and Performance, 25(1), 210-228.

Herslund, M.B. (1993). Nye reguleringsformer for cyklister i kryds (New types of regulations for bicycles at intersections). Department of Roads, Transport and Town Planning, Technical University of Denmark, Lyngby (in Danish).

Herslund, M.B. (2001). Looked-but-failed-to-see-errors i uregulerede kryds og rundkørsler (Looked-but-failed-to-see-errors at give-way intersections and roundabouts). Centre for Traffic and Transport, Technical University of Denmark, Lyngby (in Danish).

Herslund, M.B. & Jørgensen, N.O. (2003). Looked-but-failed-to-see-errors in traffic. Accident Analysis and Prevention, 35, 885–891.

Hills, B.L. (1980). Vision, visibility, and perception in driving. Perception, 9, 183-216.

Hillstrom, A.P. & Yantis, S. (1994). Visual motion and attentional capture. Perception & Psychophysics, 55, 399-411.

Hochberg, J.E. (2007). In the mind's eye: Julian Hochberg on the perception of pictures, films, and the world. New York, NY: Oxford University Press.

Hoedemaeker, M. (1999). Driving with intelligent vehicles. Doctoral Disseration, Delft University Press. Delft: The Netherlands.

Hoffman, J.E. (1998). Visual attention and eye movements. In: H. Pashler (Ed.) Attention, 119-154. London: University College London Press.

Hoffman, J.E. & Nelson, B. (1981). Spatial selectivity in visual search. Perception & Psychophysics, 30, 283-290.

Hoffman, J.E., Nelson, B. & Houck, M.R. (1983). The role of attentional resources in automatic detection. Cognitive Psychology, 15, 379-410.

Hoffman J.E. & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. Perception & Psychophysics, 57, 787-795.

Hogema, J.H. (1992). Effects of compensation for delay in the visual display of a driving simulator. TNO Report IZF 1992 A-40. Soesterberg, the Netherlands.

Hogema, J.H. (1993). Compensation for delay in the visual display of a driving simulator: effects on lane keeping. TNO Report IZF 1993 C-21. Soesterberg, the Netherlands.

Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A survey and appraisal. Behavioral and Brain Sciences, 9, 1 23.

Hollingworth, A. (2003). Failures of retrieval and comparison constrain change detection in natural scenes. Journal of Experimental Psychology: Human Perception and Performance, 29(2), 388-403.

Hollingworth, A. & Henderson, J.M. (1998). Does consistent scene context facilitate object perception? Journal of Experimental Psychology: General, 127(4), 398-415.

Hollingworth, A. & Henderson, J.M. (2002). Accurate visual memory for previously attended objects in natural scenes. Journal of Experimental Psychology: Human Perception & Performance, 28, 113-136.

Hollingworth, A., Schrock, G. & Henderson, J.M. (2001). Change detection in the flicker paradigm: The role of fixation position within the scene. Memory and Cognition, 29, 296-304.

Hollingworth, A., Williams, C.C. & Henderson, J.M. (2001). To see and remember: Visually specific information is retained in memory from previously attended objects in natural scenes. Psychonomic Bulletin & Review, 8(4), 761-768.

Hollnagel, E., Nåbo, A & Lau, I.V (2003). A systemic model for driver-in-control. Proceedings of the Second International Driving Symposium on Human Factors in Driver Assessment, training and Vehicle Design. Park City Utah, July 21-24.

Holmes, J.G. (1974). Terminology for flashing light signals. Lighting Research Technology, 6, 24.

Horowitz, T.S. & Wolfe, J.M. (1998). Visual search has no memory. Nature, 394(6693), 575-577.

Horrey, W.J., Wickens, C.D., & Consalus, K.P. (in press). Modeling drivers' visual attention allo-cation while interacting with in-vehicle technologies. Journal of Experimental Psychology: Applied.

Huettig, G., Anders, G. & Tautz, A. (1999). Mode awareness in a modern glass cockpit: Attention allocation to mode information. Proceedings of the 10th International Symposium on Aviation Psychology (CD-ROM), Columbus: Ohio State University.

Hughes, P.K. & Cole, B.L. (1986). What attracts attention when driving? Ergonomics, 29(3), 377-391.

Hughes, P.K. & Cole, B.L. (1988). The effect of attentional demand on eye-movement behavior when driving. In: A. G. Gale, M. H. Freeman, C. M. Haslegrave, P. Smith and S. P. Taylor (Eds.), Vision in vehicles II, 221–230. Amsterdam: Elsevier (North-Holland).

Humphreys, G.W. (1996). Neuropsychological aspects of visual attention and eye movements— A synopsis. In: W. H. Zangemeister (Ed.) Visual Attention and Cognition, 73 – 78. Amsterdam: Elsevier (North-Holland).

Hunt, A.R. & Kingstone, A. (2003). Covert and overt voluntary attention: linked or independent? Cognitive Brain Research, 18, 102-105.

Inhoff, A.W. (1984). Two stages of word processing during eye fixations in reading of prose. Journal of Verbal Learning and Verbal Behavior, 23, 612-624.

Inhoff, A.W., Pollatsek, A., Posner, M.I. & Rayner, K. (1989). Covert attention and eye movements during reading. Quarterly Journal of Experimental Psychology Section A, 41(1), 63-89.

Intermediair (2006). Een onbekend gevaar op de weg (An unknown danger on the road). Publication date 14th of December, 44-45. Apeldoorn: Wegener Nieuwdruk Gelderland (in Dutch).

Intraub, H. (1980). Presentation rate and the representation of briefly glimpsed pictures in memory. Journal of Experimental Psychology: Human Learning and Memory, 6, 1-12.

Intraub, H. (1981). Identification and processing of briefly glimpsed visual scenes. In: D.F. Fisher, R.A. Monty and J.W. Senders (Eds.) Eye Movements: Cognition and Visual Perception, 181-190. Hillsdale, N.J.: Lawrence Erlbaum.

Irwin, D.E., Carlson-Radvansky, L.A. & Andrews, R.V. (1995). Information processing during saccadic eye movements. Acta Psychologica, 90, 261-273.

Irwin, D.E. & Gordon, R.D. (1998). Eye movements, attention and trans-saccadic memory. Visual Cognition, 5, 127–155.

Israel, J.B., Wickens, C.D., Chesney, G.L. & Donchin, E. (1980). The event-related brain potential as an index of display-monitoring workload. Human Factors, 22, 211-224.

Itti, L. (2005). Quantifying the contribution of low-level saliency to human eye movements in dynamic scenes. Visual Cognition, 12(6), 1093-1123.

Itti, L. & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. Vision Research, 40, 1489-1506.

Itti, L., Koch, C. & Niebur, E. (1998). A model of saliency-based visual attention for rapid scene analysis. IEEE Transactions on Pattern Analysis and Machine Intelligence, 20(11), 1254–1259.

Jacoby, L.L. & Dallas, M. (1981). On the relationship between autobiographical Memory and Perceptual Learning. Journal of Experimental Psychology: General, 110 (3), 306-340.

James, W. (1890). The principles of psychology (Vol I). New York: Dover.

Jeffries, E., Lambon Ralph, M.A. & Baddeley, A.D. (2004). Automatic and controlled processing in sentence recall: The role of long -term and working memory. Journal of Memory and Language, 51, 623 -643.

Jenkins, S.E. (1982). Consideration of the effects of background on sign conspicuity. Proceedings of the 11th Australian Road Research Board (ARRB) conference, 11(5), 182-205. Melbourne.

Jerison, H.J. (1970). Vigilance, discrimination and attention. In: D.I. Mostofsky (Ed.) Attention: contemporary theory and analysis, 127-147. New York: Appleton-Century-Crofts.

Jerison, H.J. (1977). Vigilance: biology, psychology, theory and practice. In: R.R. Mackie (Ed.) Vigilance: Theory, Operational Performance and Physiological Correlates, 27–40. New York: Plenum Press.

Johansson, G. & Backlund, F. (1970). Drivers and road signs. Ergonomics, 13, 749-759.

Johansson, G. & Rumar, K. (1966). Drivers and road signs: a preliminary investigation of the capacity of car drivers to get information from road signs. Ergonomics, 9(1), 57-62.

Johnson, R.J. (1986). A triarchic model of P300 amplitude. Psychophysiology, 23, 367-384.

Johnston, W.A. & Dark, V.J. (1986). Visual Attention. Annual Review of Psychology, 37, 43-74.

Johnston, W.A. & Hawley, K.J. (1994). Perceptual inhibition of expected inputs: the key that opens closed minds. Psychonomic Bulletin and Review, 1, 56–74.

Jonides, J. (1981). Voluntary vs. automatic control over the mind's eye's movement. In: J.B. Long & A.D. Baddeley (Eds.) Attention & Performance IX, 187-203. Hillsdale, N.J.: Lawrence Erlbaum.

Jonides, J. & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. Perception & Psychophysics, 43, 346-354.

Jørgensen, E. & Jørgensen, N.O. (1994). Trafiksikkerhed i 82 danske rundkørsler—anlagt efter 1985 (Traffic safety at 82 Danish roundabouts—constructed after 1985). Danish Road Directorate, Traffic Safety and Environment, Rapport 4, Copenhagen (in Danish).

Just, M.A. & Carpenter, P.A. (1980). A theory of reading: From eye fixations to comprehension. Psychological Review, 87, 329-354.

Kahneman, D. (1973). Attention and Effort. Prentice-Hall, Inc. Englewood Cliffs, New Jersey.

Kaptein, N.A. & Theeuwes, J. (1996). Effects of road design on categorization of and expectations on 80 km/h roads (in Dutch). TNO Report TM-96-C10. Soesterberg, the Netherlands.

Kaptein, N.A., van der Horst, A.R.A. & Hoekstra, W. (1996). The effect of field of view and scene content on the validity of a driving simulator for behavioural research. TNO Report TM-96-A022. Soesterberg, the Netherlands.

Karn, K.S. & Hayhoe, M.M. (2000). Memory representations guide targeting eye movements in a natural task. Visual Cognition, 7(6), 673–703.

Kawabata, N., Yamagami, K. & Noaki, M. (1978). Visual fixation points and depth perception. Vision Research, 18, 853-854.

Kelley, T.A., Chun, M.M. & Chua, K.P. (2003). Effects of scene inversion on change detection of targets matched for visual salience. Journal of Vision, 2, 1-5.

Kerr, B. (1973). Processing demands during mental operations. Memory & Cognition, 1, 401-412.

Klein, R.M. & Pontefract, A. (1994). Does oculomotor readiness mediate cognitive control of visual attention? Revisited! In: C. Umilta and M. Moscovitch (Eds.) Attention and performance XV: Conscious and nonconscious processing, 333–350. Cambridge, MA: MIT Press.

Kleiser, R., Seitz, R.J. & Krekelberg, B. (2004). Neural correlates of saccadic suppression in humans. Current Biology, 14, 386-390.

Koch, C. & Ullman, S. (1985). Shifts in selective visual attention: towards the underlying neural circuitry. Human Neurobiology, 4, 219–227.

Koivisto, M. & Revonsuo, A. (2003).Object Recognition in the Cerebral Hemispheres as Revealed by Visual Field Experiments. Laterality: Asymmetries of Body, Brain, and Cognition, 8(2), 135-153.

Kolb, F.C. & Braun, J. (1995). Blindsight in normal observers. Nature, 377, 336-338.

Kowler, E., Anderson, E., Dosher, B. & Blaser, E. (1995). The role of attention in the programming of saccades. Vision Research, 35, 1897–1916.

Kroeber-Riel, W. (1992). Konsumentverhalten (5th Edition). Munchen: Franz Vahlen.

Kuge, N., Yamamura, T., Shimoyama, O. & Liu, A. (1998). A Driver Behavior Recognition Method Based on a Driver Model Framework. Society of Automotive Engineers Publication 2000-01-0349. Society of Automotive Engineers, Inc.

Kustov, A.A. & Robinson, D.L. (1996). Shared neural control of attentional shifts and eye movements. Nature, 384, 74–77.

Lai, D.C. (1975). Biocybernetic factor in human perception and memory. Stanford University Center for System Research, Technical Report, 6741-6745.

Land, M.F. (1995). The functions of eye movements in animals remote from man. In: J.M. Findlay, R. Walker and R.W. Kentridge (Eds.) Eye Movement Research: Mechanisms, Processes and Applications, 63-76. Elsevier: Amsterdam.

Land, M.F. & Furneaux, S. (1997). The knowledge base of the oculomotor system. Philosophical Transactions of the Royal Society of London Ser. B 352, 1231-1239.

References

Land, M.F. & Lee, D.N. (1994). Where we look when we steer. Nature, 369, 742-744.

Land, M.F., Mennie, N. & Rusted, J. (1998). Eye movements arid the roles of vision in activities of daily living: making a cup of tea. Investigative Ophthalmology & Visual Science, 39, S457 ARVO Abstract 2094.

Land, M.F., Mennie, N. & Rusted, J. (1999). Eye movements and the roles of vision in activities of daily living: making a cup of tea. Perception, 28, 1311-1328.

Land, M.F. & Nilsson, D-E. (2002). Animal Eyes. Oxford University Press.

Landman, R. (2003). Object representations in change blindness. Doctoral Dissertation Faculty of Medicine, University of Amsterdam, the Netherlands.

Lee, D.K., Koch, C. & Braun, J. (1999). Attentional capacity is undifferentiated: concurrent discrimination of form, color, and motion. Perception & Psychophysics, 61, 1241-55.

Lee, P.N.G. & Triggs, T.J. (1976). The effects of driving demand and roadway environment on peripheral visual detections. Proceedings of the Eigh[th] Conference of the Australian Road Research Board, Perth, 8 (5), 7-12.

Leibowitz, H.W. (1985). Grade crossing accidents and human factors engineering, American Scientist, 73, 558-562.

Levin, D.T. & Simons, D.J. (1997). Failure to detect changes to attended objects in motion pictures. Psychonomic Bulletin and Review, 4, 501–506.

Levin, D.T., Simons, D.J., Angelone, B.L. & Chabris, C.F. (2002). Memory for centrally attended changing objects in an incidental realworld change detection paradigm. British Journal of Psychology, 93, 289-302.

Lewicki, P., Hill, T. & Czyzewska, M. (1992). Nonconscious Acquisition of Information. American Psychologist, 47(6), 796-801.

Lewis, J.L. (1970). Semantic processing of unattended messages using dichotic listening. Journal of Experimental Psychology, 85, 220-227.

Liss, P. (1968). Does backward masking by visual noise stop stimulus processing. Perception & Psychophysics, 4, 328-330.

Liu, A. (1999). Towards predicting driver intentions from patterns of eye fixations. In: A.G. Gale et al. (Eds.) Vision in Vehicles VII, 205-211. Amsterdam: Elsevier (North Holland).

Liu, K. & Jiang, Y. (2005). Visual working memory for briefly presented scenes. Journal of Vision, 5, 650-658.

Locher, P.J. & Nodine, C.F. (1973). Influence of stimulus symmetry on visual scanning patterns. Perception and Psychophysics, 13, 408-412.

Loftus, G.R. (1983). Eye fixations on text and scenes. In: K. Rayner (Ed.) Eye Movements in Reading: Perceptual and Language Processes, 359-376. Academic Press, New York.

Loftus, E.F., Loftus, G.R. & Messo, J. (1987). Some facts about weapon focus. Law and Human Behaviour, 11, 55-62.

Loftus, G.R. & Mackworth, N.H. (1978). Cognitive determinants of fixation location during picture viewing. Journal of Experimental Psychology: Human Perception and Performance, 4(4), 565-572.

Luck, S.J. (1998). Sources of dual-task interference: Evidence From Human Electrophysiology. Psychological Science, 9(3), 223-227.

Luck, S.J. & Vogel, E. (1997). The capacity of visual working memory for features and conjunctions. Nature, 309, 279-281.

Luck, S.J., Vogel, E.K. & Shapiro, K.L. (1996). Word meanings can be accessed but not reported during the attentional blink. Nature, 383, 616 – 618.

Luck, S.J., Woodman, G.F. & Vogel, E.K. (2000). Event-related potential studies of attention. Trends in Cognitive Sciences, 4(11), 432-440.

Luoma, J. (1988). Drivers' eye fixations and perceptions. In: A.G. Gale, M.H. Freeman, C.M. Haslegrave, P. Smith and S. P. Taylor (Eds.) Vision in vehicles II, 231–237. Amsterdam: Elsevier (North-Holland).

Luoma, J. (1991). Evaluations of validity of two research methods for studying perception of road signs. Report No. UMTRI-91-15. The University of Michigan Transportation Research Institute, Ann Arbor. 1991.

MacDonald, W.A. & Hoffman, E.R. (1984). Drivers' awareness of traffic sign information. Australian Road Research Board Internal Report, AIR 382-1, Melbourne, Australia.

References

Mack, A. (2003). Inattentional blindness: looking without seeing. Current Directions in Psychological Science, 12 (5), 180–184.

Mack, A. & Rock, I. (1998). Inattentional Blindness. Cambridge, MA: MIT Press.

Mackie, R.R. (1977). Vigilance: Theory, operational performance and physiological correlates. New York: Plenum Press.

Mackworth, N.H. (1948). The breakdown of vigilance during prolonged visual search. Quarterly Journal of Experimental Psychology, 1, 6–21.

Mackworth, N.H., Kaplan, I.T. & Metlay, W. (1964). Eye movements during vigilance. Perceptual and Motor Skills, 18, 397-402.

Mackworth N.H & Morandi A.J. (1967). The gaze selects informative details within pictures. Perception and Psychophysics, 2, 547-552.

Macleod, C.M. (1991). Half a century of research on the Stroop effect: an integrative review. Psychological Bulletin, 109, 163–203.

Mandler, J.M. (1979). Categorical and schematic organization in memory. In: C.R. Puff (Ed.) Memory organization and structure, 259-299. New York: Academic Press.

Mannan, S.K., Ruddock, K.H. & Wooding, D.S. (1997). Fixation sequences made during visual examination of briefly presented 2D images. Spatial Vision, 11, 157-178.

Marcel, A.J. (1983a). Conscious and unconscious perception: experiments on visual masking and word recognition. Cognitive Psychology, 15(2), 197-237.

Marcel, A.J. (1983b). Conscious and unconscious perception: an approach to the relations between phenomenal experience and perceptual processes. Cognitive Psychology, 15(2), 238-300.

Martens, M.H. (2000). Assessing Road Sign Perception: A methodological review. Transportation Human Factors, 2(4), 347–357.

Martens, M.H. (2004). Stimuli fixation and manual response as a function of expectancies. Human Factors, 46 (3), 410-423.

Martens, M.H. (2005). Responding to changes in the traffic situation: does experience make a difference? TNO Report DV-3 2005 D018. Soesterberg, the Netherlands.

Martens, M.H. & Fox, M. (2003). Driving a familiar road: eye fixations and responses to changes. TNO Report TM-03-D017. Soesterberg, the Netherlands.

Martens, M.H. & Fox, M. (2007). Does road familiarity change eye fixations? A comparison between watching a video and real driving. Transportation Research Part F, 10(1), 33-47.

Martens, M.H. & Fox, M.J.R. (in press). Do Familiarity and Expectations Change Perception? Drivers' Glances and Response to Changes. Transportation Research Part F.

Martens, M.H. & Slegers, K. (2002). The role of expectations and implicit conjunctions on target detection and eye movements. TNO Report TM-02-D007. Soesterberg, the Netherlands.

Matin, L. (1972). Eye movements and perceived visual direction. In: D. Jameson and L.M. Hurvich (Eds.) Handbook of sensory physiology VII/4: Visual psychophysics. Berlin: Springer-Verlag.

Matin, E. (1974). Saccadic suppression: A review and an analysis. Psychological Bulletin, 81, 899-917.

McCarley, J.S., Vais, M.J., Pringle, H., Kramer, A.F., Irwin, D.E. & Strayer, D.L. (2004). Conversation disrupts change detection in complex traffic scenes. Human Factors, 46(3), 424-436.

McConkie, G.W. & Currie, C.B. (1996). Visual stability across saccades while viewing complex pictures. Journal of Experimental Psychology: Human Perception and Performance, 22, 563–581.

McConkie, G.W. & Zola, D. (1979). Is visual information integrated across successive fixations in reading? Perception and Psychophysics, 25, 221–224.

McCormick, P.A. (1997). Orienting attention without awareness. Journal of Experimental Psychology: Human Perception and Performance, 23, 168-180.

McLay, R.W., Anderson, D.J., Sidaway, B. & Wilder, D.G. (1997). Motorcycle accident reconstruction under Daubert. Journal of the National Academy of Forensic Engineering, 14, 1–18.

McLeod, P., McLaughlin, C. & Nimmo-Smith, I. (1985). Information encapsulation and automaticity: Evidence from the visual control of finely timed actions. In: M.I. Posner and O.S.M. Marin (Eds.) Attention and Performance XI, 391-406. Hillsdale, N.J.: Lawrence Erlbaum

McPeek, R., Maljkovic, V. & Nakayama, K. (1999). Saccades require focal attention and are facilitated by a short-term memory system. Vision Research, 39, 1555-1565.

Melcher, D. (2001). The persistance of memory for scenes. Nature, 412, 401.

Mermall, T. (1970). Spain's philosopher of hope. Thought, 45 (176), 104-120.

Meyers, L.S. & Rhoades, R.W. (1978). Visual search of common scenes. Quarterly Journal of Experimental Psychology, 30, 297-310.

Miller, J. (1989). The control of attention by abrupt visual onsets and offsets. Perception & Psychophysics, 45(6), 567-571.

Milosevic, S. & Gajic, R. (1986). Presentation factors and driver characteristics affecting road-sign registration. Ergonomics, 29(6), 807-815.

Mitroff, S.R., Simons, D.J. & Franconeri, S.L. (2002). The siren song of implicit change detection. Journal of Experimental Psychology: Human Perception and Performance, 28(4), 798-815.

Moffit, K. (1980). Evaluation of the fixation duration in visual search. Perception and Psychophysics, 27, 370-372.

Moore, C.M. (2001). Inattentional blindness: Perception or memory and what does it matter? Psyche, 7(2), retrieved from http://psyche.cs.monash.edu.au/v7/psyche-7-02-moore.html

Moore, C.M. & Egeth, H. (1997). Perception without attention: Evidence of grouping under conditions of inattention. Journal of Experimental Psychology: Human Perception and Performance, 23, 339-352.

Moore, T. & Fallah, M. (2001). Control of eye movements and spatial attention. Proceedings of the National Academy of Sciences, 98(3), 1273-1276.

Moore, T. & Fallah, M. (2004). Control of eye movements and spatial attention. Journal of Neurophysiology, 91, 152-162.

Moray, N. (1986). Monitoring behavior and supervisory control . In: K. Boff, I. Kaufmann and J. Beatty (Eds.) Handbook of perception and human performance, Vol. 2: Cognitive processes and performance, 1-51. New York, Wiley-Interscience.

Mori, M. & Abdel-Halim, M.H. (1981). Road sign recognition and non recognition. Accident Analysis and Prevention, 13, 101-115.

Most, S.B., Clifford, E., Scholl, B.J. & Simons, D.J. (2000). What you see is what you set: The role of attentional set in explicit attentional capture. Poster presented at Object perception and Memory (OPAM), New Orleans, LA.

Most, S.B., Scholl, B.J., Clifford, E.R. & Simons, D.J. (2005). What you see is what you set: Sustained Inattentional Blindness and the capture of awareness. Psychological Review, 112 (1), 217–242.

Most, S.B., Simons, D.J., Scholl, B.J. & Chabris, C.F. (2000). Sustained inattentional blindness: The role of location in the detection of unexpected dynamic events. Psyche, 6(14). Retrieved from http://psyche.cs.monash.edu.au/v6/psyche-6 14-most.html.

Most, S.B., Simons, D.J., Scholl, B.J., Jimenez, R., Clifford, E. & Chabris, C.F. (2001). How not to be seen: The contribution of similarity and selective ignoring to sustained inattentional blindness. Psychological Science, 12, 9–17.

Müller, H.J. & Rabbitt, P.M.A. (1989). Reflexive and voluntary orienting of visual attention: Time course of activation and resistance to interruption. Journal of Experimental Psychology: Human Perception and Performance, 15, 315-330.

Näätänen, R. & Summala, H. (1976). Road-user behavior and traffic accidents. Amsterdam: North-Holland.

Naveh-Benjamin, M. & Jonides, J. (1986). On the automaticity of frequency coding: Effects of competing task load, encoding strategy, and intention. Journal of Experimental Psychology: Learning, Memory, and Cognition, 12, 378-386.

Navon, D. & Gopher, D. (1979). On the economy of the human-processing system. Psychological Review, 86(3), 214-255.

Neider, M.B. & Zelinsky, G.J. (2006). Searching for camouflaged targets: effects of target-background similarity on visual search. Vision Research, 46(14), 2217-2235.

Neisser, U. & Becklen, R. (1975). Selective looking: Attending to visually specified events. Cognitive Psychology, 7, 480–494.

Neumann, O. (1987). Beyond capacity: a functional view of attention. In: H. Heuer & A.F. Sanders (Eds.) Perspectives on Perception and Action, 361-394. Hillsdale, N.J.: Lawrence Erlbaum.

Newby, E. A. & Rock, I. (1998). Inattentional blindness as a function of proximity to the focus of attention. Perception, 27, 1025–1040.

Niebur, E. & Koch, C. (1996). Control of selective visual attention: Modeling the "where" pathway. In: D.S. Touretzky, M.C. Mozer and M.E. Hasselmo (Eds.) Advances in Neural Information Processing Systems, 8, 802–808. Cambridge, M.A.: MIT Press.

References

Niedeggen, M., Wichmann, P. & Stoerig, P. (2001). Change blindness and time to consciousness. European Journal of Neuroscience, 14, 1719–1726.

Nisbett, R.E. & Wilson, T. (1977). Telling more than we can know: Verbal Reports On Mental Processes. Psychological Review, 84(3), 231-259.

Norman, D. & Bobrow, D. (1975). On data-limited and resource-limited processes. Cognitive Psychology, 7, 44-64.

Noton, D. & Stark, L. (1971a). Eye movements and visual perception. Scientific American, 224, 34-43.

Noton, D. & Stark, L. (1971b). Scanpaths in eye movements during pattern perception. Science, 171, 308-311.

Noton, D. & Stark, L. (1971c). Scanpaths in saccadic eye movements while viewing and recognizing patterns. Vision Research, 11, 929-942.

O'Regan, J.K. (2001). Thoughts on Change Blindness. In: M. Jenkin and L. Harris (Eds.) Vision & Attention, 281-301. Springer-Verlag, New York.

O'Regan, J.K., Deubel, H., Clark, J.J. & Rensink, R.A. (2000). Picture changes during blinks: Looking without seeing and seeing without looking. Visual Cognition, 7, 191–211.

O'Regan, J.K., Rensink, R.A. & Clark, J.J. (1996). "Mud splashes" render picture changes invisible. Investigative Opthalmology and Visual Science (Suppl.), 37(3), 213.

O'Regan, J.K., Rensink, R.A. & Clark, J.J. (1999). Change-blindness as a result of "mudsplashes". Nature, 398, 34.

Paap, K.R., McDonald, J.E., Schvaneveldt, R.W. & Noell, R.W. (1987). Frequency and pronounceability effects in visually presented naming and lexical decision tasks. In: M. Coltheart (Ed.) Attention and Performance XII: The Psychology of Reading, 221-243. Hillsdale, N.J.: Erlbaum.

Paine, R.F. (1969). Brightness and brightness ratio as factors in the attention value of highway signs. Highway Research Record, 275, 32.

Parasuraman, R. (1984). Sustained attention in detection and discrimination. In: R. Parasuraman and D.R. Davis (Eds.) Varieties of Attention, 243–271. New York: Academic Press.

Parasuraman, R., Molloy, R. & Singh, E.L. (1993). Performance consequences of automation-induced 'complacency'. International Journal of Aviation Psychology, 3(1), 1-23.

Parker, R.E. (1978). Picture processing during recognition. Journal of Experimental Psychology: Human Perception and Performance, 4, 284-293.

Parkhurst, D. & Niebur, E. (2004). Salience and overt visual attention. Available at http://www.cn.stir.ac.uk/ecovision-ws/pdf/78.pdf.

Pashler, H. (1988). Familiarity and visual change detection. Perception and Psychophysics, 44(4), 369–378.

Pashler, H.E. (1998). The psychology of attention. MIT Press, Cambridge, MA.

Patten, C.J.D., Kircher, A., Östlund, J. & Nilsson, L. (2004). Using mobile telephones: Cognitive workload and attention resource allocation. Accident Analysis & Prevention, 36, 341-350.

Pearson, P.M. & Schaefer, E.G. (2005). Toupee or not toupee? The role of instructional set, centrality, and relevance in change blindness. Visual Cognition, 12 (8), 1528-1543.

Phillips, W.A. & Singer, W. (1974). Function and interaction of on and off transients in vision I: Psychophysics. Experimental Brain Research, 19(5), 493-506.

Picton, T.W., Hillyard, S.A., Krausz, H.I. & Galambos, R. (1974). Human auditory evoked potentials I: Evaluation of components. Electroencephalogry and Clinical Neurophysiology, 36, 179-190.

Pollatsek, A. & Rayner, K. (1982). What is integrated across saccades? In: K. Rayner (Ed.) Eye movement and visual cognition: Scene perception and reading. New York: Springer Verlag, 166-191.

Posner, M.I. (1978). Chronometric Explorations of the Mind. Lawrence Erlbaum Associates.

Posner, M.I. (1980). Orienting of attention. Quarterly Journal of Experimental Psychology, 32, 3-25.

Posner, M.I., Snyder, C.R.R. & Davidson, B.J. (1980). Attention and the detection of signals. Journal of Experimental Psychology: General, 109, 160-174.

Potter, M.C. (1975). Meaning in visual search. Science, 187, 965-966.

Potter, M.C. (1976). Short-term conceptual memory for pictures. Journal of Experimental Psychology: Human Learning and Memory, 2(5), 509-522.

References

Potter, M.C. & Levy, E.I. (1969). Recognition memory for a rapid sequence of pictures. Journal of Experimental Psychology, 81(1), 10-15.

Pringle, H.L., Irwin, D.E., Kramer, A.F. & Atchley, P. (2001). The role of attentional breadth in perceptual change detection. Psychonomic Bulletin & Review, 8(1), 89-95.

Pylyshyn, Z.W. & Storm, R.W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. Spatial Vision, 3(3), 179-197.

Quist, B. (1988). The application of human error models in accident hypothesis formulation. In: J.A. Rothengatter and R.A. de Bruin (Eds.) Road user behaviour, theory and research, 26-31. New Hampshire, USA: Van Gorcum & Company.

Rakauskas, M.E., Ward, N.J., Bernat, E.M., Cadwallader, M., Patrick, C.J. & de Waard, D. (2005). Psychophysiological measures of driver distraction and workload while intoxicated. Poster 3rd International Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design. Rockport, Maine.

Räsänen, M. & Summala, H. (1998). Attention and expectation problems in bicycle-car collisions: An in-depth study. Accident Analysis and Prevention, 30, 657-666.

Räsänen, M., Summala, H. & Pasanen, E. (1998). The safety effects of sight obstacles and road markings at bicycle crossings. Traffic Engineering and Control, 39, 98–103.

Rashbass, C. (1961). The relationship between saccadic and smooth tracking eye movements. Journal of Physiology (London), 159, 326-338.

Rasmussen, J. (1986). Information processing and human-machine interaction. An approach to cognitive engineering. North-Holland series in System Science and Engineering. Series Volume 12, USA.

Rayner, K. (1977). Visual attention in reading: Eye movements reflect cognitive processes. Memory and Cognition, 4, 443-448.

Rayner, K. (1978). Foveal and parafoveal cues in reading. In: J. Requin (Ed.) Attention and Performance VII, 149-161. Hillsdale, NJ: Erlbaum.

Rayner, K. & Duffy, S.A. (1986). Lexical complexity and glance durations in reading: Effects of word frequency, verb complexity, and lexical ambiguity. Memory and Cognition, 14, 191-201.

Rayner, K. & Pollatsek, A. (1989). The psychology of reading. Englewood Cliffs, N.J.: Pentice-Hall.

Rayner K. & Pollatsek A. (1992). Eye movements and scene perception. Canadian Journal of Psychology. 46, 342-376

Reber, A.S. (1989). Implicit learning and tacit knowledge. Journal of Experimental Psychology: General, 118, 219-235.

Recarte, M.A. & Nunes, L.M. (2000). Effects of verbal and spatial imagery task on eye fixations while driving. Journal of Experimental Psychology: Applied, 6, 31–43.

Recarte, M.A. & Nunes, L.M. (2003). Mental workload while driving: Effects on visual search, discrimination, and decision making. Journal of Experimental Psychology: Applied, 9(2), 119-137.

Reingold, E.M., Charness, N., Pomplun, M. & Stampe, D.M. (2001). Visual span in expert chess players: Evidence from eye movements. Psychological Science, 12, 48-55.

Renge, K. (1980). The effects of driving experience on driver's visual attention. An analysis of objects looked at: using the 'verbal report' method. International Association of Traffic Safety Research, 4, 95-106.

Rensink, R.A. (2000a). The dynamic representation of scenes. Visual Cognition, 7, 17-42.

Rensink, R.A. (2000b). Seeing, sensing, and scrutinizing. Vision Research, 40, 1469-1487.

Rensink, R.A. (2002). Change detection. Annual Review of Psychology, 53, 245-277.

Rensink, R.A., O'Regan, J.K. & Clark, J.J. (1997). To see or not to see: the need for attention to perceive changes in scenes. Psychological Science, 8(5), 368-373.

Richard, C.M., Wright, R.D., Ee, C., Prime, S.L., Shimizu, Y. & Vavrik, J. (2002). Effect of a concurrent auditory task on visual search performance in a driving-related image-flicker task. Human Factors, 44(1), 108-119.

Rizzolatti, G., Riggio, L., Dascola, I. & Umilta, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. Neuropsychologica, 25, 31–40.

Rizzolatti, G., Riggio, L. & Sheliga, B.M. (1994). Space and selective attention. In C. Umilta and M. Moscovitch (Eds.) Attention and performance XV: Conscious and nonconscious information processing, 231–265. Cambridge, MA: MIT Press.

Rock, I., Linnett, C.M., Grant, P. & Mack, A. (1992). Perception without attention: Results of a new method. Cognitive Psychology, 24, 502–534.

Rohrbaugh, J.W. (1984). The orienting reflex: Performance and central nervous system manifestations. In: R. Parasuraman and D.R. Davies (Eds.) Varieties of attention, 323-374. San Diego CA: Academic Press.

Rumar, K. (1990). The basic driver error: late detection. Ergonomics, 33(10/11), 1281-1290.

Rumelhart, D.E. (1976). Understanding and summarizing brief stories. In: D. LaBerge and S.J. Samuels (Eds.) Basic processes in reading: Perception and comprehension, 265-303. Lawrence Erlbaum Associates.

Ryan, J.D., Althoff, R.R., Whitlow, S. & Cohen, N.J. (2000). Amnesia is a deficit in declarative (relational) memory. Psychological Science, 11, 454–461.

Ryan, J.D. & Cohen, N.J. (2004). The nature of change detection and online representations of scenes. Journal of Experimental Psychology: Human Perception and Performance, 30(5), 988-1015.

Salthouse, T.A., Ellis, C.L., Dienier, D.C. & Somberg, B.L. (1981). Stimulus processing during eye fixations. Journal of Experimental Psychology: Human Perception and Performance, 7, 611-623.

Sarter, N.B., Mumaw, R.J. & Wickens, C.D. (2007). Pilots' monitoring strategies and performance on automated flight decks: An empirical study combining behavioral and eye-tracking data. Human Factors, 49(3), 347-357.

Sarter, N.B. & Woods, D.D. (1997). Teamplay with a powerful and independent agent: A corpus of operational experiences and automation surprises on the Airbus A-320. Human Factors, 39(4), 553-569.

Sarter, N.B. & Woods, D.D. (2000). Team play with a powerful and independent agent: a full-mission simulation study. Human Factors, 42(3), 390-402.

Saylor, M.M. & Baldwin, D.A. (2004). Action analysis and change blindness: possible links. In: D.T. Levin (Ed.) Thinking and seeing. Visual metacognition in adults and children, 37-56. Cambridge, MA: MIT Press.

Schank, R. & Abelson, R. (1977). Scripts, plans, goals and understanding: An inquiry into human knowledge structures. Hillsdale, N.J.: Lawrence Erlbaum.

Schneider, W.X. & Deubel, H. (1995). Visual attention and saccadic eye movements: Evidence for obligatory and selective spatial coupling. In: J.M. Findlay, R. Walker and R.W. Kentridge (Eds.) Eye movement research, 317–324. Amsterdam: Elsevier (North Holland).

Schneider, W., Dumais, S.R. & Shiffrin, R.M. (1984). Varieties of attention. New York: Academic Press.

Schneider, W. & Shiffrin, R.M. (1977). Controlled and automatic human information processing: 1. Detection, search, and attention. Psychological Review, 84(1), 1-66.

Scholl, B.J. (2000). Attenuated Change Blindness for exogenously attended items in a flicker paradigm. Visual Cognition, 7(1/2/3), 377-396.

Scholl, B.J., Noles, N.S., Pasheva, V. & Sussman, R. (2003). Talking on a cellular telephone dramatically increases "sustained inattentional blindness." Paper presented at the annual meeting of the Vision Sciences Society, Sarasota, FL.

Sciolino, E. (2001). Military in curb on civilian visits. New York Times, February 24, 1.

Scremec, B. (1973). Perception of traffic signs. Proceedings of XVII International Congress, 1455-1457. Brussels: Editest.

Sharpless, S. & Jasper, H. (1956). Habituation of the arousal effect. Brain, 79(4), 655-680.

Shebilske, W. (1975). Reading eye movements from an information-processing point of view. In: D. Massaro (Ed.) Understanding Language, 291-311. New York: Academic Press.

Shepherd, M., Findlay, J.M. & Hockey, R.J. (1986). The relationship between eye movements and spatial attention. Quarterly Journal of Experimental Psychology, 38A, 475-491.

Sheridan, T. (1981). Understanding human error and aiding human diagnostic behavior in nuclear power plants. In: J. Rasmussen and W. Rouse (Eds.) Human detection and diagnosis of system failures, 19-35. New York: Plenum Press.

Shiffrin, R.M. (1976). Capacity limitations in information processing, attention, and memory. In: W.K. Estes (Ed.) Handbook of learning and cognitive processes: Vol. 4. Attention and memory, 177-236. Hillsdale, N.J.: Erlbaum.

Shiffrin, R.M., Dumais, S.T. & Schneider, W. (1981). Characteristics of automatism. In: J. Long and A.D. Baddeley (Eds.) Attention and performance IX, 223-238. Hillsdale, N.J.: Erlbaum.

Shiffrin, R.M. & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. Psychological Review, 84, 127-190.

Shinar, D. & Drory, A. (1983). Sign registration in daytime and night time driving. Human Factors, 25, 117-122.

Simons, D.J. (1996). In sight, out of mind: When object representations fail. Psychological Science, 7, 301–305.

Simons, D.J. (2000). Attentional capture and inattentional blindness. Trends in Cognitive Sciences, 4, 147–155.

Simons, D.J. & Chabris, C.F. (1999). Gorillas in our midst: sustained inattentional blindness for dynamic events. Perception, 28(9), 1059-1074.

Simons, D.J., Chabris, C.F., Schnur, T. & Levin, D.T. (2002). Evidence for preserved representations in change blindness. Consciousness and Cognition, 11, 78–97.

Simons, D.J., Franconeri, S.L. & Reimer, R.L. (2000). Change blindness in the absence of a visual disruption. Perception, 29(10), 1143-1154.

Simons, D.J. & Levin, D.T. (1997). Change blindness. Trends in Cognitive Sciences, 1(7), 261–267.

Simons, D.J. & Levin, D.T. (1998). Failure to detect changes to people during real-world interaction. Psychonomic Bulletin and Review, 4(5), 644–649.

Simons, D.J. & Mitroff, S.R. (2001). The role of expectations in change detection and attentional capture. In: M. Jenkin and L. Harris (Eds.) Vision & Attention, 189-207. Springer-Verlag, New York.

Smilek, D., Eastwood, J.D. & Merikle, P.M. (2000). Does unattended information facilitate change detection? Journal of Experimental Psychology: Human Perception and Performance, 26(2), 480-487.

Smilek, D., Eastwood, J.D., Reynolds, M.G. & Kingstone, A. (2007). Metacognitive errors in change detection: Missing the gap between lab and life. Consciousness and Cognition, 16, 52-57.

Smith, E. (1968). Choice reaction time: An analysis of the major theoretical positions. Psychological Bulletin, 69, 77-110.

Snoeren, P.R. & Puts, M.J.H. (1997). Multiple parameter estimation in an adaptive psychometric method: MUEST, an extension of the QUEST method. Journal of Mathematical Psychology, 41(4), 431-439.

Sperling, G. (1960). The information available in brief visual presentation. Psychological Monographs: General and Applied, 74, 1-29.

Sperling, G. (1967). Successive approximations to a model for short-term memory. Acta Psychologica, 27, 285-292.

Sperling, G. & Weichselgartner, E. (1995). Episodic theory of the dynamics of spatial attention. Psychological Review, 102, 503-532.

Stadler, M.A. & Frensch, P.A. (1998). Handbook of implicit learning. Thousand Oaks, CA: Sage.

Stark, L. & Ellis, S.R. (1981). Scanpaths revisited: Cognitive models direct active looking. In: D.F. Fisher, R.A. Monty & J.W. Senders (Eds.) Eye Movements: Cognition and Visual Perception, 193-226. Hillsdale, NJ: Lawrence Erlbaum Associates.

Staughton, G.C. & Storie, V.J. (1977). Methodology of an in-depth accident investigation. Survey Report No. 672, Transport and Road Research Laboratory, Crowthorne, Berks.

Stelmach, L.B., Bourassa, C.M. & Di Lollo, V. (1984). Detection of stimulus change: the hypothetical roles of visual transient responses. Perception & Psychophysics, 35(3), 245-255.

Sternberg, S. (1969). The discovery of processing stages: Extension of Donders' method. Acta Psychologica, 30, 276-315.

Strayer, D.L., Crouch, D.J. & Drews, F.A. (2004). A comparison of the cell phone driver and the drunk driver. AEI-Brookings Joint Center Working Paper No. 04-13. Available at SSRN: http://ssrn.com/abstract=570222

Strayer, D.L., Drews, F.A. & Crouch, D.J. (2003). Fatal distraction? A comparison of the cell-phone driver and the drunk driver. Proceedings of the Second International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design, 25-30. Iowa City: Driving Assessment, University of Iowa.

Stroop, J. (1935). Studies of interference in serial verbal interactions. Journal of Experimental Psychology, 18, 643-662.

Summala, H. & Hietamäki, J. (1984). Drivers' immediate responses to traffic signs. Ergonomics, 27, 205-216.

Summala, H., Pasanen, E., Räsänen, M. & Sievänen, J. (1996). Bicycle accidents and drivers' visual search at left and right turns. Accident Analysis and Prevention, 28 (2), 147–153.

Talgar, C., Pelli, D.G. & Carrasco, M. (2004). Covert attention enhances letter identification without affecting channel tuning. Journal of Vision, 4(1), 22–31.

Taylor, S.E. & Crocker, J. (1981). Schematic bases of social information processing. In: E.T. Higgins, C.P. Herman and M.P. Zanna (Eds.) Social Cognition: the Ontario symposium, Vol. 1, 89-134. Hillsdale, NJ, Erlbaum.

Theeuwes, J. (1989). Effects of location and form cuing on the allocation of attention in the visual field. Acta Psychologica, 72, 177-192.

Theeuwes, J. (1990). Perceptual selectivity is task-dependent: evidence from selective search. Acta Psychologica, 74, 81-99.

Theeuwes, J. (1991a). Cross-dimensional perceptual selectivity. Perception & Psychophysics, 50, 184-193.

Theeuwes, J. (1991b). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. Perception & Psychophysics, 49 (1), 83-90.

Theeuwes, J. (1991c). Visual search of traffic scenes. Report No IZF 1991 C-18. Soesterberg: TNO Institute for Perception.

Theeuwes, J. (1992a). Selective attention in the visual field. Doctoral dissertation, Free University, Amsterdam.

Theeuwes, J. (1992b). Perceptual selectivity for colour and form. Perception & Psychophysics, 51, 599-606.

Theeuwes, J. (1992c). Visual search at intersections: an eye-movement analysis. Report No IZF 1992 C-43. Soesterberg: TNO Institute for Perception.

Theeuwes, J. (1993). Visual selective attention: a theoretical analysis. Acta Psychologica, 83, 93-154.

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: selective search for color and visual abrupt onsets. Journal of Experimental Psychology: Human Perception and Performance, 20, 799-806.

Theeuwes, J. (1996). Visual search at intersections: An eye movement analysis. In: A.R. Gale (Ed.) Vision in Vehicles V, 125-134. Amsterdam: Elsevier (North-Holland).

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Theeuwes, J. & Godijn, R. (2004). Inhibition-of-return and oculomotor interference. Vision Research, 44, 1485–1492.

Theeuwes, J., Kramer, A.F, Hahn, S. & Irwin, D.E. (1998). Our eyes do not always go where we want them to go: capture of the eyes by new objects. Psychological Science, 9, 379-385.

Theeuwes, J., Kramer, A.F., Hahn, S., Irwin, D.E. & Zelinsky, G.J. (1999). Influence of attentional capture on oculomotor control. Journal of Experimental Psychology: Human Perception and Performance, 25(6), 1595-1608.

Thornton, I.M. & Fernandez-Duque, D. (2000). An implicit measure of undetected change. Spatial Vision, 14(1), 21-44.

Tinker, M.A. (1939). Reliability and validity of eye-movement measures of reading. Journal of Experimental Psychology, 19, 732-746.

Tipper, S.P. & Driver, J. (1988). Negative priming between pictures and words in a selective attention task: evidence for semantic processing of ignored stimuli. Memory & Cognition, 16(1), 64-70.

Tipper, S.P. & Weaver, B. (1998). Visual Attention. Oxford University Press.

Treisman, A.M. (1988). Features and objects: The fourteen[th] Bartlett memorial lecture. Quarterly Journal of Experimental Psychology, 40, 201-237.

Treisman, A. & Gelade, G. (1980). A feature integration theory of attention. Cognitive Psychology, 12, 97-136.

Turatto, M., Angrilli, A., Mazza, V., Umilta, C.A. & Driver, J. (2002). Looking without seeing the background change: Electrophysiological correlates of change detection versus change blindness. Cognition, 84, B1-B10.

Tzelgov, J. (1997). Specifying the relations between automaticity and consciousness: A theoretical note. Consciousness and Cognition, 6, 441-451.

Tzelgov, J. (2000). On processing in the inattention paradigm as automatic. Psyche, 6(17), http://psyche.cs.monash.edu.au/v6/psyche-6-17-tzelgov.html

Uetake, A. & Murata, A. (2000). Assessment of mental fatigue during VDT task using event-relatedpotential (P300). Proceedings 9th IEEE International Worksop on Robot and Human Interactive Communication, 235-240. Osaka, Japan.

Underwood, G. (1974). Moray vs. the rest: The effects of extended shadowing practice. Quarterly Journal of Experimental Psychology, 26, 368–372.

Underwood, G., Chapman, P., Berger, Z. & Crundall, D. (2003). Driving experience, attentional focusing, and the recall of recently inspected events. Transportation Research Part F (6), 289-304.

Underwood, G. & Everatt, J. (1992). The role of eye movements in reading: some limitations of the eye-mind assumption. In: E. Chekaluk and K.R. Llewellyn (Eds.) The role of eye movements in perceptual processes, 111-169. Amsterdam: Elsevier (North-Holland).

Van der Heijden, A.H.C. (1992). Selective attention in vision. London: Routledge.

Van der Hulst, M., Meijman, T. & Rothengatter, T. (1999). Anticipation and the adaptive control of safety margins in driving. Ergonomics, 42, 336-345.

Van Duren, L.L. (1994). Signal processing during eye fixations and saccades. Dissertation at the Free University of Amsterdam, the Netherlands. 12th of September 1994.

Van Elslande, P. & Faucher-Alberton, L. (1997). When expectancies become certainties: A potential adverse effect of experience. In: T. Rothengatter and E. Carbonell Vaya (Eds.) Traffic and transport psychology: theory and application, 147–159. Oxford: Pergamon Press.

VanRullen, R. & Koch, C. (2003). Competition and selection during visual processing of natural scenes and objects. Journal of Vision, 3(1), 75-85.

Van Winsum, W. & Godthelp, J. (1996). Speed choice and steering behavior in curve driving. Human Factors, 38(3), 434-441.

Verghese, P. & Nakayama, K. (1994). Stimulus discriminability in visual search. Vision Research, 34(18), 2453-2467.

Viviani, P. (1990). Eye movements in visual search: Cognitive, perceptual and motor control aspects. In: E. Kowler (Ed.) Eye Movements and Their Role in Visual and Cognitive Processes, 353-394. Amsterdam: Elsevier (Nort-Holland).

Vogel, E.K., Luck, S.J. & Shapiro, K.L. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. Journal of Experimental Psychology: Human Perception and Performance, 27, 92-114.

Volkmann, F.C. (1976). Saccadic suppression: A brief review. In: R.A. Monty and J.W. Senders (Eds.) Eye Movements and Psychological Processes, 73-83. Hillsdale, NJ: Erlbaum.

Volkmann, F.C. (1986). Human visual suppression. Vision Research, 26, 1401-1416.

Von Helmholtz, H. (1909). Helmholtz's physiological optics (1866/1911). Translated from the third edition (1909 – 1911) by J.P. Southwell (Ed.). Rochester, New York: Optical Society of America.

Vuillemier, P., Sagiv, N., Hazeltine, E., Poldrack, R., Rafal, R. & Gabrielli, J. (2001). The neural fate of seen and unseen faces in visuo-spatial neglect: A combined event-related fMRI and ERP studt of visual extinction. Proceedings of the National Academy of Science, USA, 98, 3495-3500.

Warm, J.S. (1977). Psychological processes in sustained attention. In: R.R. Mackie (Ed.) Vigilance: theory, operational performance and physiological correlates, 623-644. New York: Plenum.

Watson, A.B. & Pelli, D.G. (1983). QUEST: a Bayesian adaptive psychometric method. Perception & Psychophysics, 33, 113-120.

Welford, A.T. (1976). Skilled Performance. Glenview, IL: Scott, Foresman.

Werner, S. & Thies, B. (2000). Is "Change Blindness" attenuated by domain-specific expertise? An expert–novices comparison of change detection in football images. Visual Cognition, 7(1/2/3), 163-173.

Westheimer, G. (1954). Eye movement responses to a horizontally moving visual stimulus. Archives of Ophthalmology N.Y., 52, 932-941.

Wickens, C.D. (1980). The structure of attentional resources. In: R. Nickerson (Ed.) Attention and Performance VIII, 239-257. Hillsdale, N.J.: Erlbaum.

Wickens, C.D. (1984). Engineering psychology and human performance. Columbus, Ohio: Bell & Howell.

Wickens, C.D. (2002). Multiple resources and performance prediction. Theoretical issues in ergonomics science, 3(2), 159-177.

Wickens, C.D., Goh, J., Helleberg, J., Horrey, W., & Talleur, D.A. (2003). Attentional models of multitask pilot performance using advanced display technology. Human Factors, 45(3), 360–380.

Wickens, C.D., Helleberg, J., Goh, J., Xu, X., & Horrey, B. (2001). Pilot task management:Testing an attentional expected value model of visual scanning (ARL-01-14/NASA-01-7). Savoy: University of Illinois, Aviation Research Laboratory.

Wickens, C., Israel, J. & Donchin, E. (1977). The event-related cortical potential as an index of task workload. In: A.S. Neal and R.F. Palasek (Eds.) Proceedings of the Human Factors Society 21st Annual Meeting. San Francisco.

Widdel, H. & Kaster, J. (1981). Eye movement measurement in the assessment and training of visual performance. In: J. Moraal and K.F. Kraiss (Eds.) Manned systems design, methods, equipment and applications, 251-270. New York: Plenum.

Wiener, E.L. (1984). Vigilance and inspection. In: J.S. Warm (Ed.) Sustained attention in human performance, 207-246. New York: John Wiley & Sons Ltd.

Williams, P. & Simons, D. J. (2000). Detecting changes in novel, complex three-dimensional objects. Visual Cognition, 7, 297–322.

Wirtschafter, J.D. & Weingarden, A.S. (1988). Neurophysiology and central pathways in oculomotor control: Physiology and anatomy of saccadic and pursuit eye movements. In: C.W. Johnston and F.J. Pirozzolo (Eds.) Neuropsychology of eye movements, 5-29. Hillsdale, N.J.: Lawrence Erlbaum.

Wolfe, J.M. (1999). Inattentional Amnesia. In: V. Coltheart (Ed.) Fleeting memories: Cognition of brief visual stimuli, 71-94. Cambridge, MA: MIT Press.

Wolfe, J.M., Cave, K.R. & Frantzel, S.L. (1989). Guided search: An alternative to the feature integration model for visual search. Journal of Experimental Psychology: Human Perception and Performance, 15, 419-433.

Yantis, S. (1996). Attentional capture in vision. In: A. F. Kramer, M.G.H. Coles and G.D. Logan (Eds.) Converging operations in the study of visual attention, 45-76. Washington, DC: American Psychological Association.

Yantis, S. (1998). Control of visual attention. In: H. Pashler (Ed.) Attention, 13-74. Psychology Press, Hove, UK.

Yantis, S. (2000). Goal directed and stimulus driven determinants of attentional control. In: S. Monsell and J. Driver (Eds.) Attention and performance XVIII: Control of cognitive processes, 71-104. Cambridge, MA: MIT Press.

Yantis, S. & Jonides, J. (1984). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. Journal of Experimental Psychology: Human Perception and Performance, 16, 121-134.

Yantis, S. & Jonides, J. (1996). Attentional capture by abrupt onsets: New perceptual objects or visual masking? Journal of Experimental Psychology: Human Perception and Performance, 22(6), 1505-1513.

Yarbus, A. (1967). Eye movement and vision. New York: Plenum Press.

Yerkes, R.M. & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit formation. Journal of Comparative and Neurology and Psychology, 18, 459–482.

Zusne, L. & Michels, K.M. (1964). Nonrepresentational shapes and eye movements. Perceptual and Motor Skills, 18, 11-20.
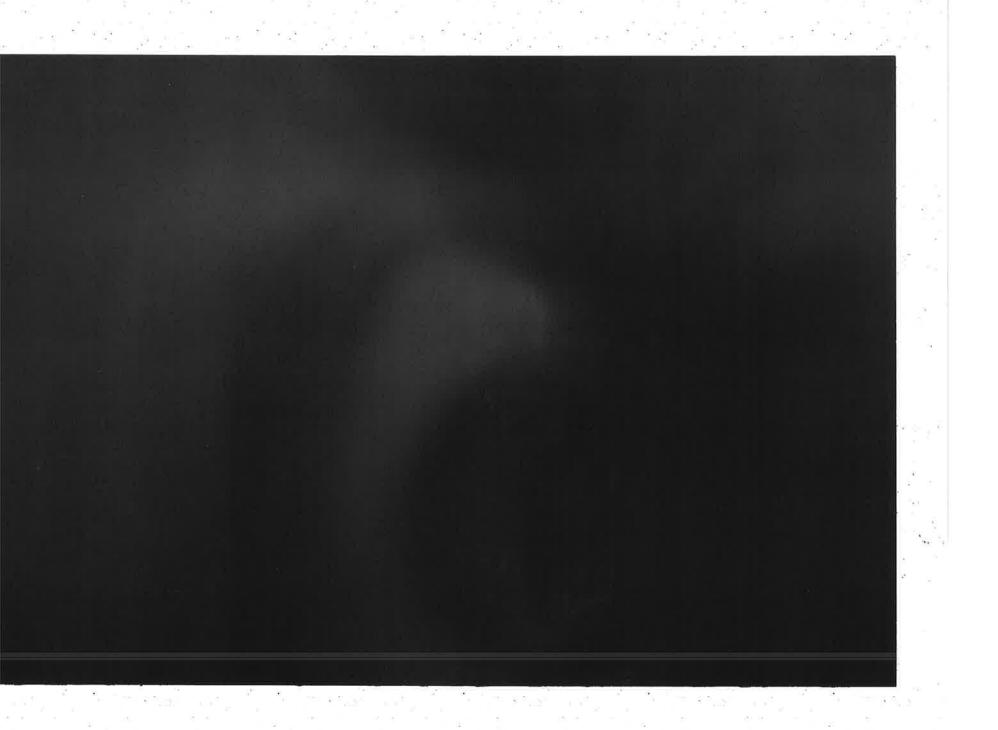
Zwahlen, H.T. (1981). Driver eye scanning of warning signs on rural highways. Proceedings of the 25th Annual Meeting of the Human Factors Society, 33-37. October, Rochester NY.
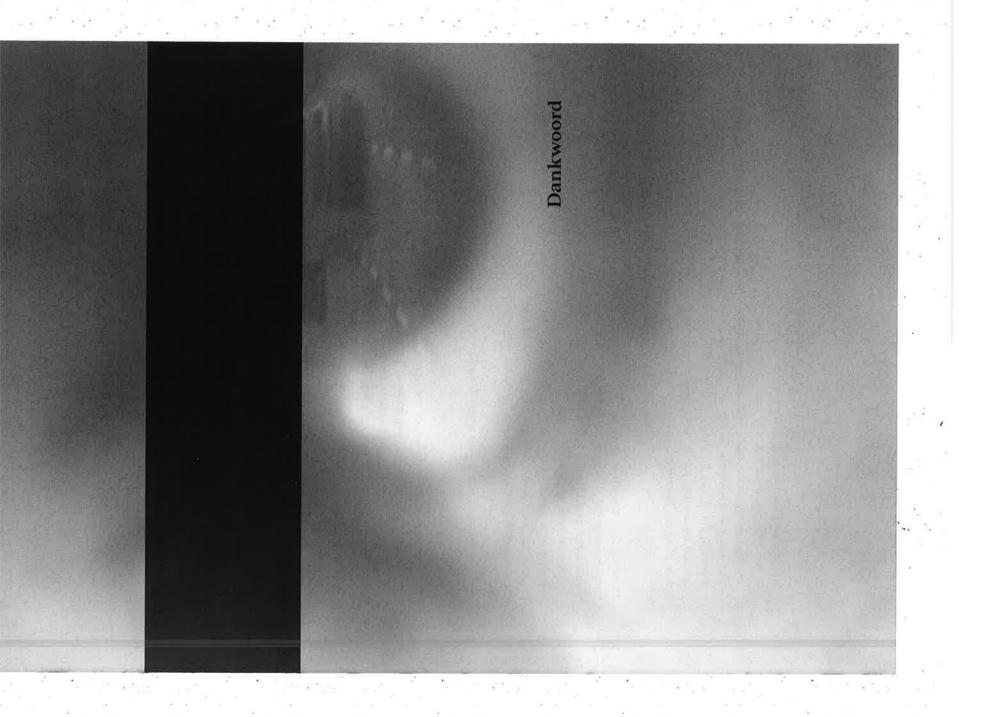
Zwahlen, H.T. (1987). Advisory speed signs and curve signs and their effect on driver eye scanning and driving performance. Transportation Research Record 1111, 110-120. Transportation Research Board, National Research Council, Washington, DC.

Zwahlen, H.T. (1988). Stop ahead and stop signs and their effect on driver eye scanning and driving performance. Transportation Research Record 1168,16-24. Transportation Research Board, National Research Council, Washington, DC.

Zwahlen H.T. (1995). Traffic sign reading distances and sign reading times when driving at night. Transportation Research Record 1495, 140-146. Transportation Research Board, National Research Council, Washington, DC.

Zwahlen, H.T., Russ, A. & Schnell, T. (2002). Driver eye scanning behavior while viewing ground-mounted diagrammatic guide signs before entrance ramps at night. Paper No. 03-2686, prepared for Presentation at the 82nd Annual Meeting of the Transportation Research Board, January 12-16, 2003. National Academy of Sciences Washington, DC.

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Dankwoord

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Curriculum Vitae

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Marieke Martens was born on the 28th of December 1971 in Breda. After graduating at the 'Stedelijk Gymnasium' in 1990, she went to study psychology at the Free University in Amsterdam. After two general years she decided to choose Experimental and Cognitive Psychology with Professor Dr A.F. Sanders. After some experimental work concerning the useful field of view at the Free University, she went for a 6 month internship to the Aviation Research Laboratory (University of Illinois, USA). Together with Professor Dr C.D. Wickens she worked in the area of visual clutter in displays and the possibilities for improving visual search performance by means of highlighting and low lighting information. In 1995 she was an intern at TNO Human Factors at the department of Information Processing working in the field of task allocation at the Dutch Navy. She finished her studies in May 1996. In May 1996 she started working at the Traffic Behaviour group at TNO Human Factors as a researcher in the area of road design, driver support systems, tunnels, dynamic information, eye movements and visual attention. In 2001 she became coordinator of the traffic behaviour group. The work of her doctoral dissertation has been done as part of a funding of the Dutch Ministry of Transport and has its origin in 2000. In 2000 Marieke spent 6 months as a guest researcher at VTI in Linköping (Swedish National Road and Transport Research Institute. Since 2005 she is Senior Research Scientist of the department of Human Performance.